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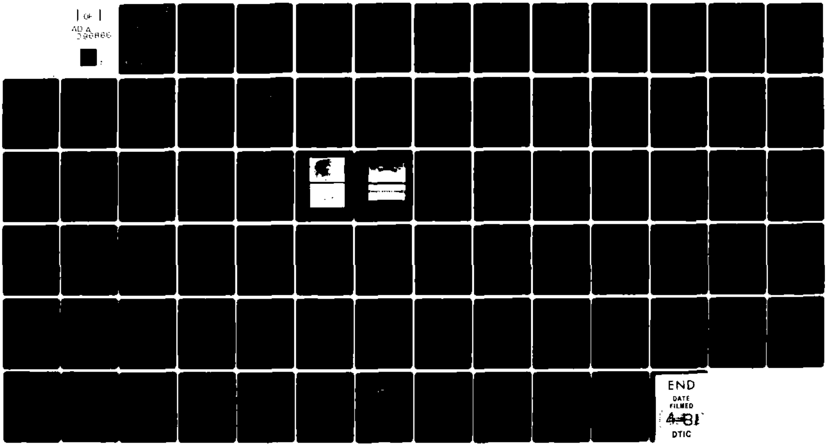

CAORF 90-7801-01

VALIDATION OF COMPUTER AIDED OPERATIONS RESEARCH FACILITY (CAORF)

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This report documents the CAORF Validation Studies conducted during CAORF acceptance testing and the early research experimentation phases. The specific areas of validation were hardware, information processing and behavioral validation. The validation testing to date indicates that:

- (1) The simulated ship reacts as its real world equivalent does.
- 2 The bridge equipment and visual scene react realistically to position and heading changes of ownship and traffic vessels.
- The realism of the visual scene and radar display has been deemed satisfactory by experienced subjects.
- Accuracy in distance estimation can be achieved by training.
- Behavior on the CAORF bridge is similar to real-world behavior and provides valid research and training data.

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VALIDATION
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COMPUTER AIDED OPERATIONS RESEARCH FACILITY
(CAORF)

By

CAORF Research Staff

Prepared For

National Maritime Research Center
Kings Point, New York 11024

January 1979

ABSTRACT

This report documents the Computer Aided Operations Research Facility (CAORF) validation studies that have taken place during CAORF acceptance testing and the early research experimentation phases. Validation was required to demonstrate that the level of CAORF realism is sufficiently close to the real-world situation, under similar circumstances, so that the maritime industry can confidently rely on the research data and conclusions that result from CAORF experimentation.

Specific areas of validation as reported herein comprise hardware, information processing and behavioral validation. The validation testing accomplished to date indicates that:

- The simulated ship reacts to changes in engine speed and rudder angle as the real-world equivalent does.

- The bridge equipment and visual scene react realistically to position and heading changes of ownship and traffic vessels.

- The realism of the visual scene and radar display has been deemed satisfactory by experienced mariners.

- The only difficulty detected in the area of information processing was the ability to estimate distances of target ships accurately from the visual display. This problem has been successfully overcome with the precondition of familiarization training.

- Behavioral patterns on CAORF are sufficiently similar to real-world behavior to provide valid research and training data.

ACKNOWLEDGEMENTS

This research was performed under Contract 5-38003 by the Grumman Data Systems Corporation as Research Facility Managers of the Computer Aided Operations Research Facility (CAORF) and by Eclectech Associates, consultants to Grumman Data Systems Corporation. It was sponsored by the Office of Commercial Development of the United States Maritime Administration, U. S. Department of Commerce and was monitored by the National Maritime Research Center.

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CHAPTER 1

INTRODUCTION

The purpose of the Computer Aided Operations Research Facility (CAORF) validation is to demonstrate that the simulator represents a real-world ship and its environment with sufficient accuracy to permit its use in experiments investigating maritime problems. This report presents the results of the initial validation of the new simulator which was conducted during CAORF acceptance testing and the early research experimentation phases. For a description of CAORF, see Appendix C.

The studies conducted in 1976 involved three aspects of CAORF validation, as outlined below:

a. Hardware Validation (Chapter 2)

   1. Ownship's response characteristics

   2. Accuracy of visual scene (e.g., target aspect and size as a function of range and visibility limitations)

   3. Accuracy of data bases

b. Visual Perception Validation (Chapter 3)

   The mate's perceptual integration of simulated information

c. Behavioral Validation (Chapter 4)

   1. Validation data base

   2. Validation analysis

CHAPTER 2

HARDWARE VALIDATION

2.1 INTRODUCTION

In the validation of the CAORF hardware, three areas are addressed: ownship's response characteristics and their similarity to real-world ship responses (2.2); the accuracy of the CAORF visual scene in representing real-world conditions (2.3); and the visual, radar and situation display data bases (2.4).

2.2 OWNSHIP'S RESPONSE CHARACTERISTICS

In order for research and training efforts associated with CAORF to produce valid results, it is vital that the response characteristics of ownship be simulated realistically. The mathematical model should represent, as closely as possible, an actual ship. Since it is impossible to duplicate every aspect of the real world, however, the success of the simulation depends on careful selection of appropriate characteristics. For CAORF simulation, it was decided that ownship should have reasonably accurate hydrodynamics, that it should respond with proper delays and speed changes to new engine orders, and that its handling characteristics should be representative of the type of ship simulated. It was considered unnecessary, however, for the CAORF wheelhouse to pitch and roll as a real ship would in heavy seas. Before final validation, comments of professional mariners, such as ship masters and pilots, were solicited and modifications were made to improve the realism of ownship response characteristics. A selection of these comments is contained in Appendix A.

Two methods of validating CAORF ownship's response characteristics were used: comparison with an off-line non-real time computer simulation and with actual sea-trial data. Ship hydrodynamic coefficients, propulsion coefficients, and physical dimensions defining an 80,000 DWT tanker were used.

2.2.1 *Validation by Off-Line Computer Simulation*

The CAORF mathematical model was based on documentation furnished by Dr. H. Eda, Resident Hydrodynamicist at Davidson Laboratory, Stevens Institute of Technology. Davidson Laboratory uses a generalized non-real time computer program for general simulation. It therefore differs from the real-time CAORF program with respect to some of the algorithms

such as integration (e.g., rectangular vs. trapezoidal). CAORF utilizes engine and propeller models whereas Davidson Laboratory uses a proprietary model.

The simulated ship was an 80,000 DWT tanker. Validation of the CAORF model was performed for various maneuvers, starting with an approach speed of 15 knots.

Figure 2.1 shows various turning circles for the Davidson Laboratory model. In addition, the figure depicts a turning circle from trial data for an actual 80,000 DWT tanker. It can be seen that there is very close agreement for the turning circles obtained with the rudder angle set for 35 degrees. Figure 2.2 shows trajectories for Davidson Laboratory and CAORF ship hydrodynamics. It can be seen that the trajectories match each other closely except that the CAORF model lags in time. This lag is attributable to the modifications made to the CAORF model to incorporate comments of professional mariners.

2.2.2 Validation by Comparison with Sea-Trial Data

To support CAORF validation, CAORF real-time test data were also compared with actual sea-trial data. To demonstrate ship dynamics, the exercises consisted of turning circles, Z (zig-zag) maneuvers, and spiral tests. However, since sea trials can vary not only for different ships of the same class, but also for the same ship, and since test results depend on such parameters as wind, current, draft, trim, and conditions of the hull, comparisons of sea-trial data with CAORF data must be tempered by an allowance for variability in the sea-trial data. A discussion of comparative results for each of the aforementioned maneuvers follows.

a. Turning Circles - The deep water turning circles of CAORF compare favorably with the sea-trial data of a similar size vessel. Figure 2.3 shows a plot of a right-turn circle by CAORF simulation and Figure 2.4, a right-turn circle from the sea-trial data of an 80,000 DWT tanker under equivalent conditions. From the figures, we can make the following comparisons:

Source of Data	Advance (ft)	Maximum Transfer(ft)	Transfer (ft)
CAORF	2309	2370	932
80,000 DWT Tanker	2285	2660	950

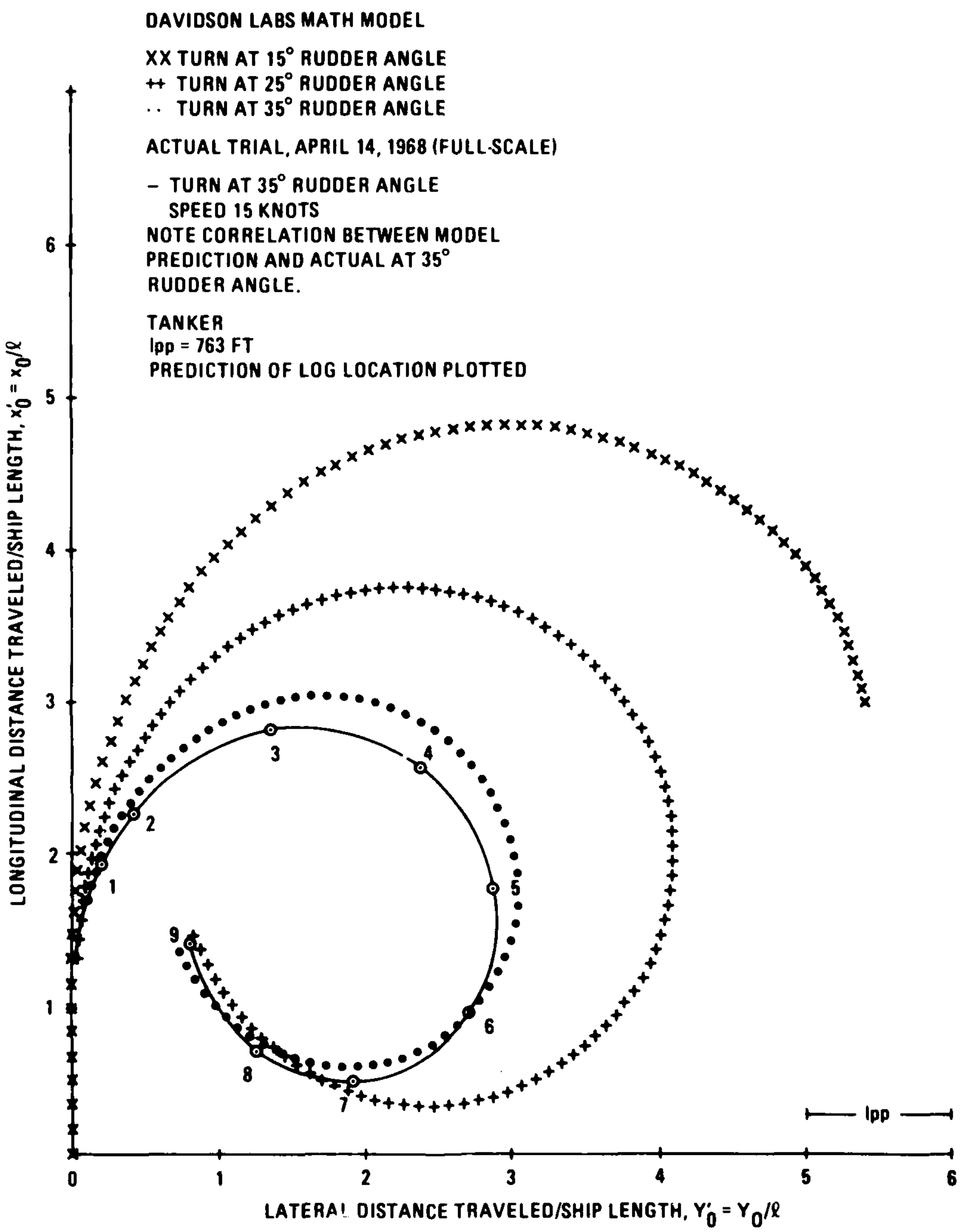

Figure 2.1. Turning Trajectories of 80,000 DWT Tankers - Math Model and Actual Trial

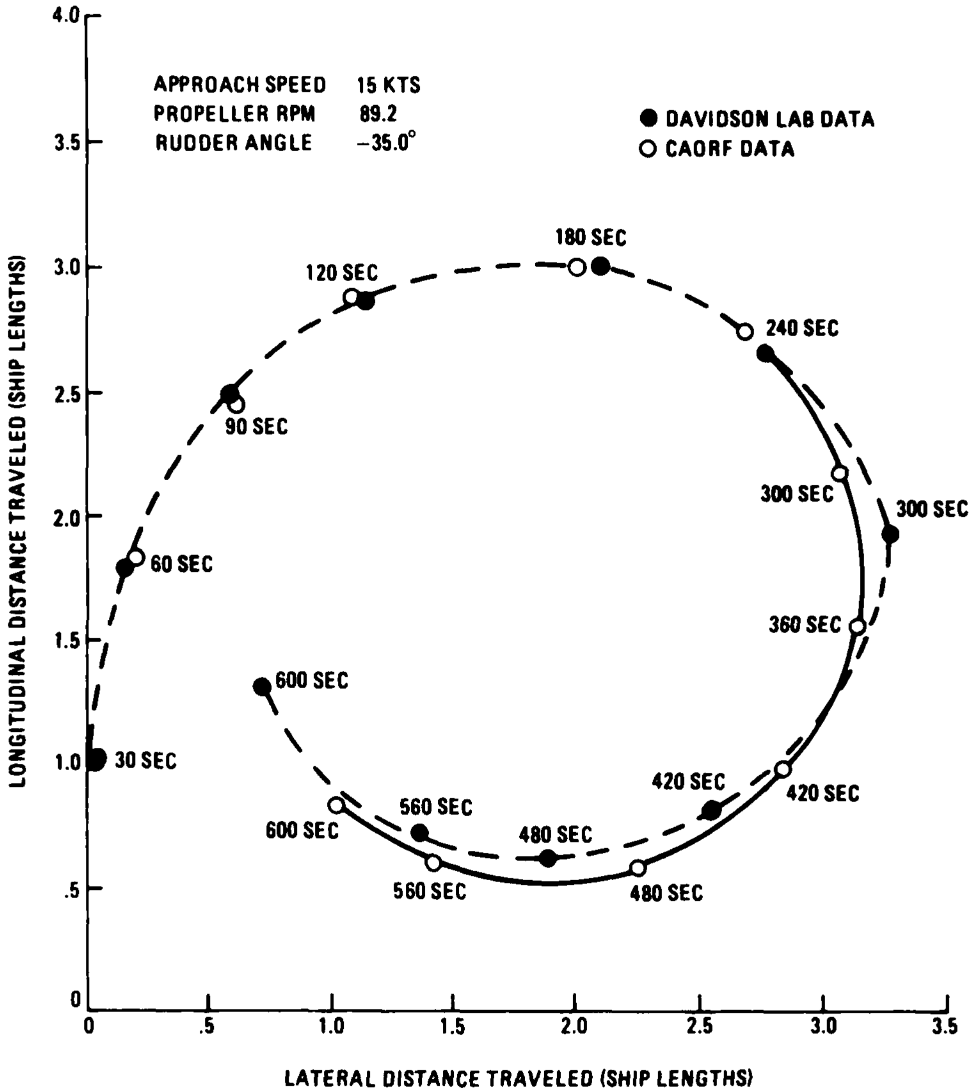

Figure 2.2. Comparison of Turning Circles

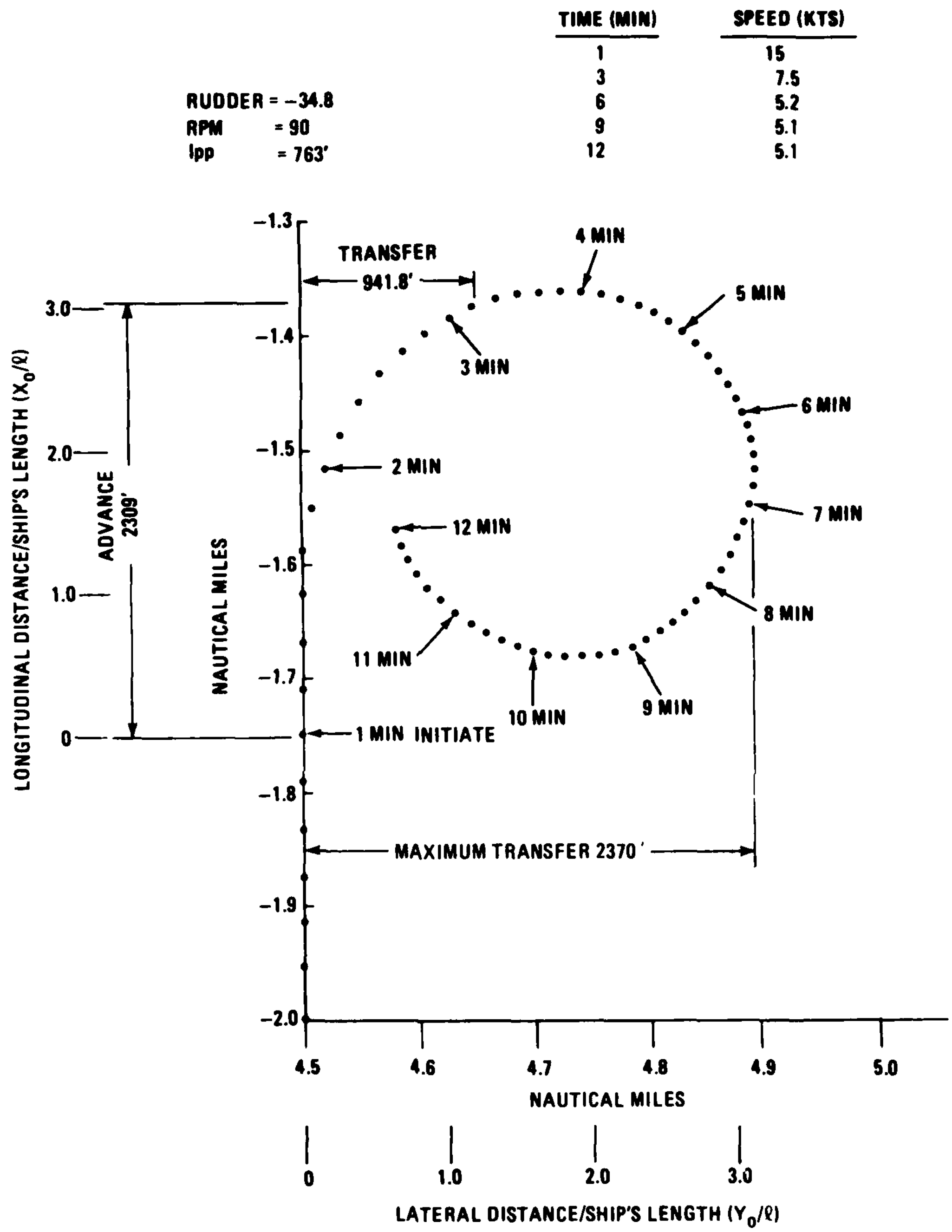

Figure 2.3. CAORF Right-Turn Circle

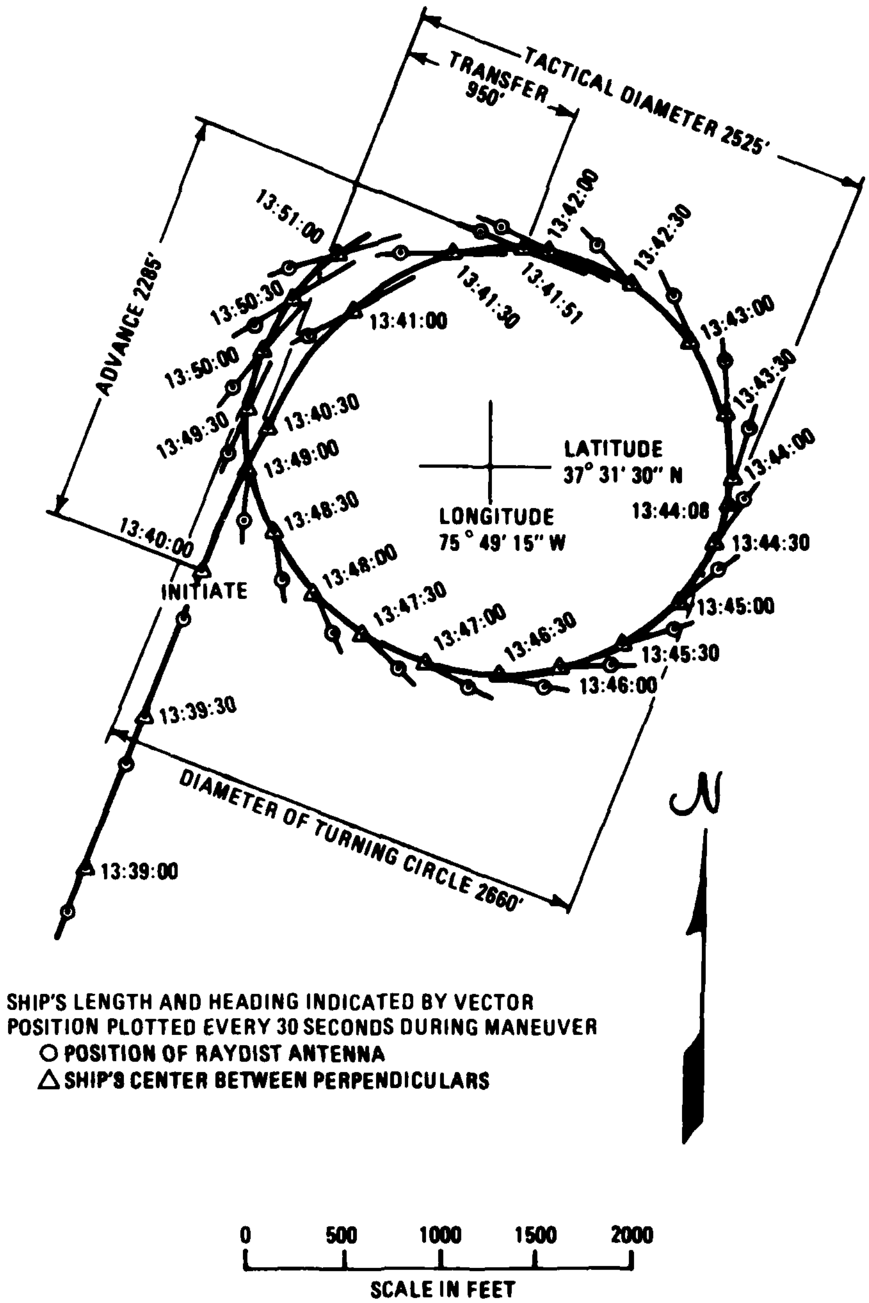

Figure 2.4. 80,000 DWT Tanker's Right-Turn Circle

Another area of favorable comparison is that of the slow-down effect in performing a turn. From Figure 2.4 it is estimated that ship's speed was reduced from an initial speed of 17 knots to 6.6 knots. The data shown in Figure 2.3 for the CAORF ship indicate a reduction from an initial speed of 15 knots to 5.1 knots. Thus, CAORF slow-down data (38.8 percent of initial speed) is comparable to actual ship data (34 percent). (It must be remembered that CAORF was operating under no-wind, no-current conditions.) Figure 2.5 shows the turning circles obtained on CAORF with different rudder angles.

b. Z Maneuver - The Z (or overshoot) maneuver demonstrates the ability of a rudder to control a vessel when initiating or checking turns. The results of such a test depend primarily on rudder effectiveness and the dynamic stability of the ship. Results are also dependent on speed. The important measures in this maneuver are shown in Figure 2.6 and are the time to reach second execute (t_o) and the overshoot yaw angle (delta psi).

The Z maneuver is executed as follows: The ship is on a steady course at full sea speed. (Exact sea speed is optional.) At time zero, the rudder is put over 20^o right. This is known as the first execute of the Z maneuver. The rudder is kept 20^o right until the ship changes course 20^o. The time it takes for the ship to change course 20^o is known as the time to second execute, at which time the rudder is set at 20^o left. Time to reach second execute is a measure of the ability of a ship to change course. In general, the time to reach second execute decreases with increased speed. The ship will continue swinging right for a while even though the rudder is at 20^o left. When the vessel is checked, maximum course deviation is reached. The amount by which the maximum course deviation exceeds the heading at second execute is known as the yaw overshoot angle (delta psi). The yaw overshoot angle increases with increased speed and is a measure of the countermaneuvering ability of a ship. It provides an indication of the amount of anticipation required of a helmsman. The yaw overshoot angle decreases with increased dynamic stability, but increases with increased rudder effectiveness. The rudder is kept at 20^o left until the vessel is 20^o to the left of the original course. When this occurs the helm is put over 20^o right, the third execute.

The 20°-20° Z maneuver on CAORF shows an overshoot yaw angle at second execute of 12.3° (see Figure 2.7). The subsequent executes produce overshoots of approximately 10 degrees. The same maneuver with a 75,000 DWT tanker (Figure 2.8) yields overshoots of 13° for the second execute and 8° for the third execute. Since such ships have effective rudders, the CAORF modeled tanker's response appears reasonable. Comments of experienced ship captains indicate that when CAORF is put into swing and counter rudder is applied, the course is checked in a realistic amount of time and with a reasonable amount of overshoot.

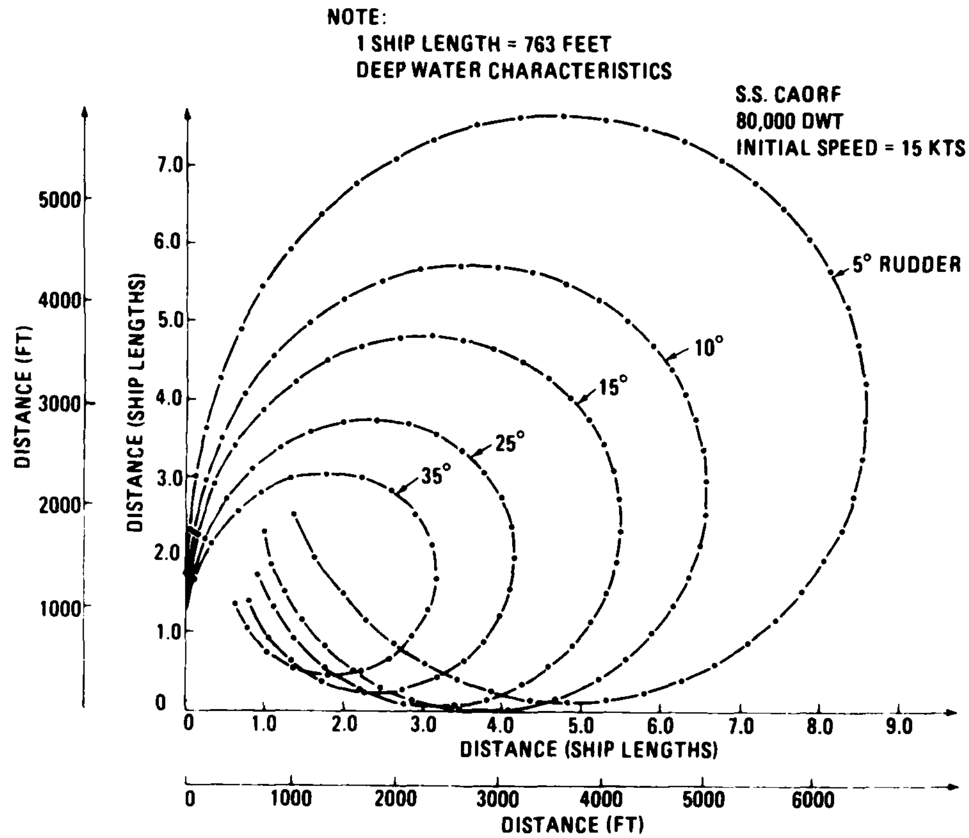

Figure 2.5. CAORF's Right-Turn Circles at Different Rudder Angles

c. Spiral Maneuver - The spiral maneuver serves mainly to determine the dynamic stability characteristics of a ship. A distinction should be made between dynamic stability and directional stability, with which it is sometimes erroneously equated. Directional stability, illustrated as Case I in Figure 2.9, is not a characteristic of a

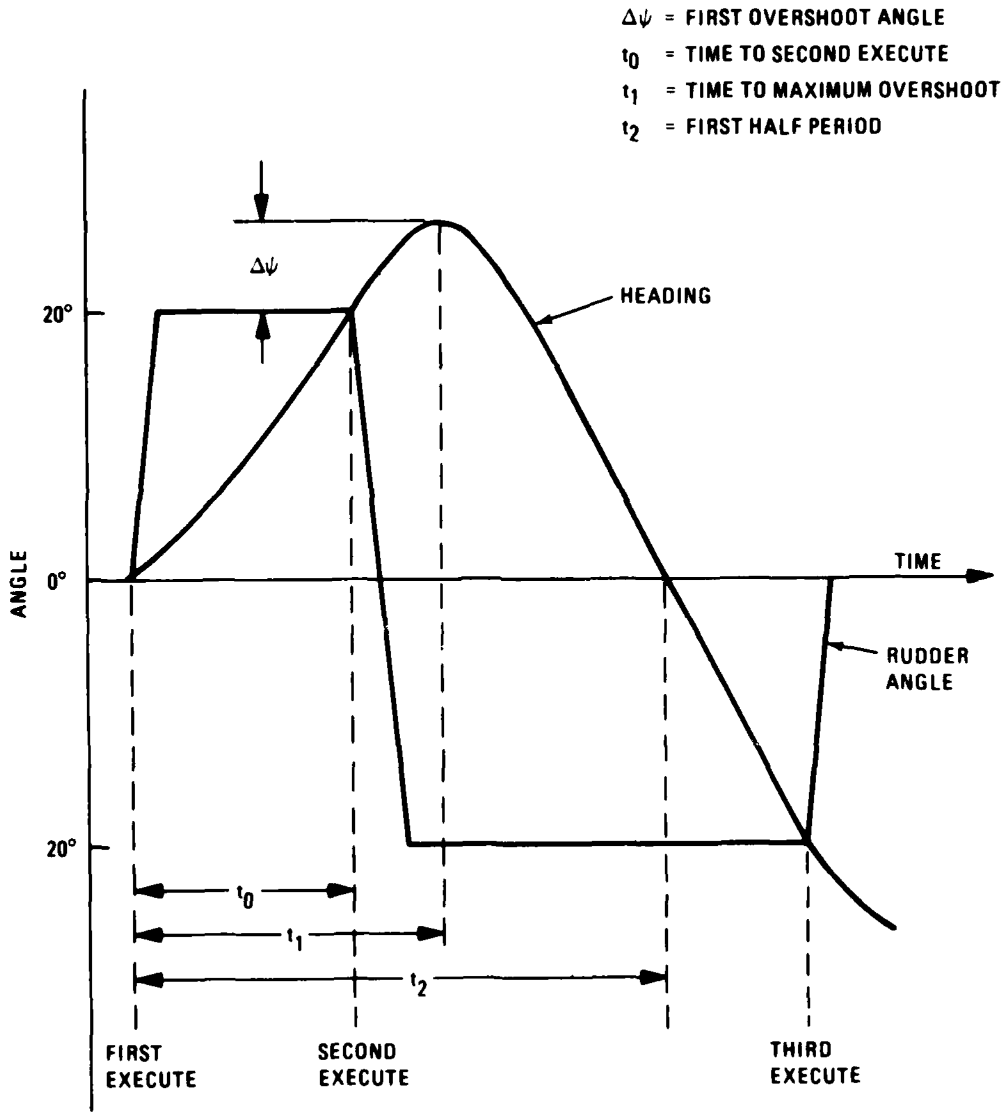

Figure 2.6. Z Maneuver Measures

ship itself, but of the ability of its pilot or helmsman to maintain a course. Dynamic stability (straight line stability), illustrated as Case II in Figure 2.9, is an inherent characteristic of a ship.

Assuming that a ship is initially on a steady course (no turn rate) when it is subjected to an external force, the ship will deviate from its original course with a proportionate rate of turn. The ship will continue to turn as long as the external force is applied. When the external force is removed, the ship will slowly lose its turn momentum and steady on a new course (rate of turn equal to zero) if the ship is dynamically stable.

If the ship is dynamically unstable, it will continue to turn for an extended period of time after the external force is removed.

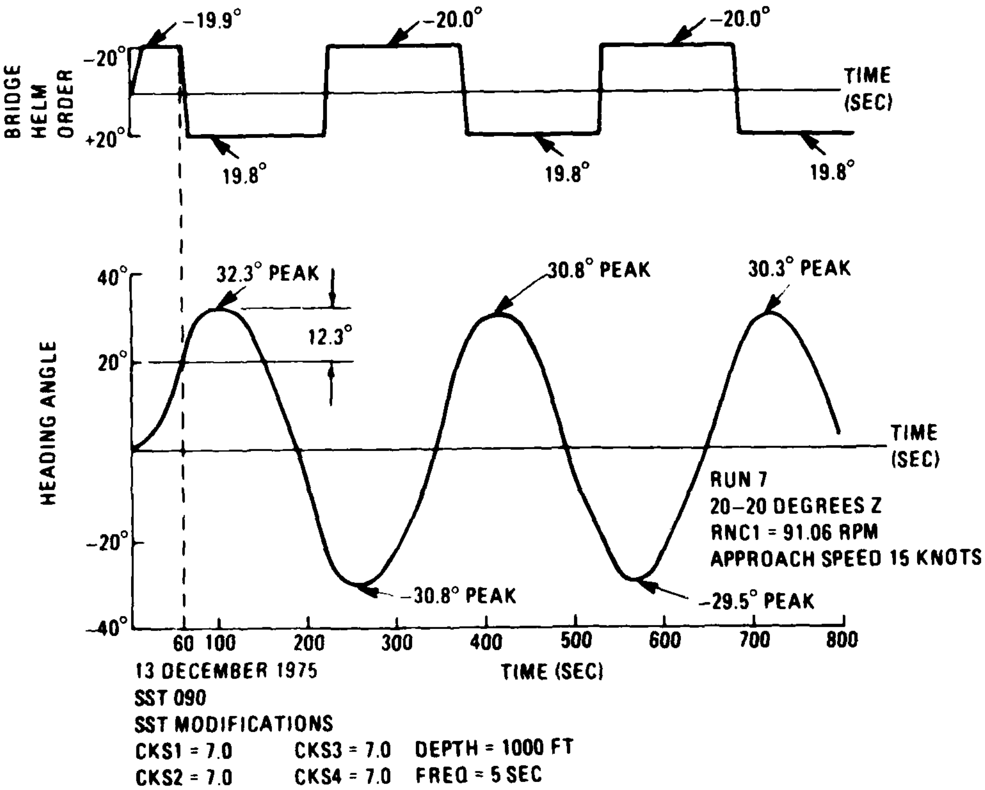

Figure 2.7. Z Maneuver - CAORF Ship

The spiral maneuver is performed with a ship on a steady course (zero turn rate) and at full speed ahead (although other speeds can also be used). The rudder is turned to approximately 15° right and held there until the rate of turn is maintained at constant value for approximately one minute. After one minute, the rudder angle is decreased about 5° and held fixed until the rate of turn becomes constant and remains so for several minutes. The procedure is repeated for small incremental changes in rudder angle, starting from large values of starboard rudder to large values of port rudder and back again to large starboard values. Numerical measures are obtained from the spiral maneuver for the turn rate (angular velocity) as a function of rudder angle. The results of such a test for CAORF are plotted in Figure 2.10. CAORF is an unstable ship as indicated by the hysteresis loop, which shows that angular velocity does not return to zero when the rudder is returned to zero. There is at this time no comparable sea-trial data on the spiral test; the only data available are from tests on free-running models. However, professional mariners have characterized CAORF as being realistically unstable.

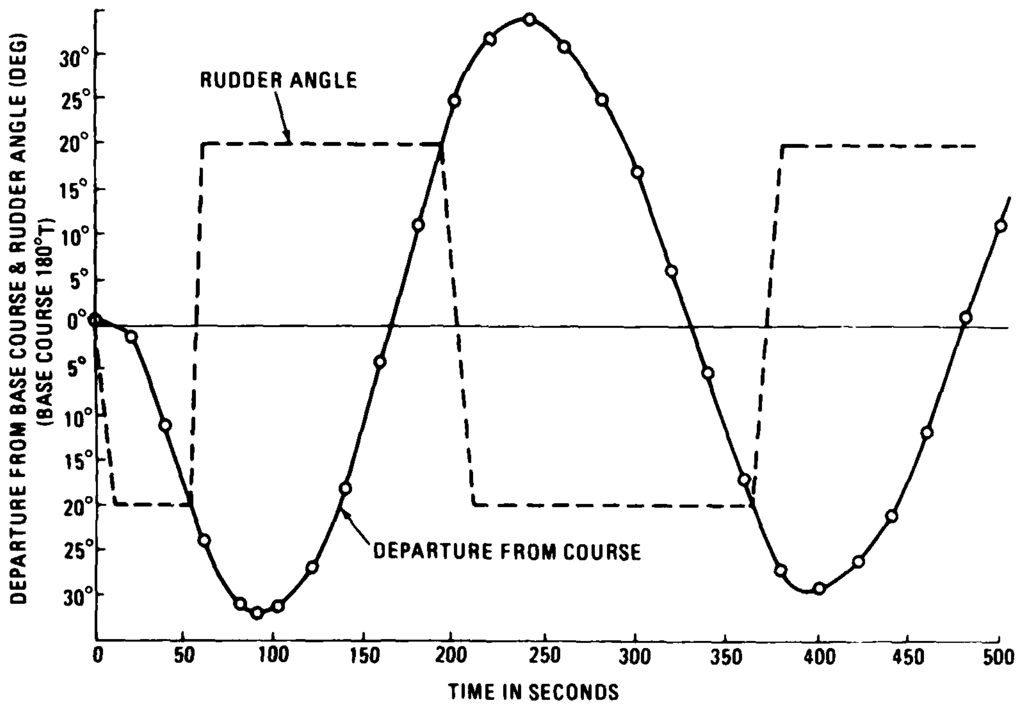

Figure 2.8. Z Maneuver - 75,000 DWT Tanker

2.3 VISUAL SCENE ACCURACY

The size of traffic ships displayed at different ranges on the simulator's projection screen were measured, and these measurements compared favorably with theoretical vessel sizes for the same ranges. The results, which are plotted in Figures 2.11 through 2.16, show very good agreement between the measured and calculated values. This allows accurate estimation of traffic ranges and positive identification of target ships.

2.4 VISUAL, RADAR, AND SITUATION DISPLAY DATA BASES

CAORF utilizes three different kinds of data bases to accomplish the required simulation: the visual environment data base (VEDB), the radar environment data base, and the situation display data base. The data bases were developed from slides, pictures, sketches, drawings, standard and topographic maps, nautical charts, and lists of appropriate objects.

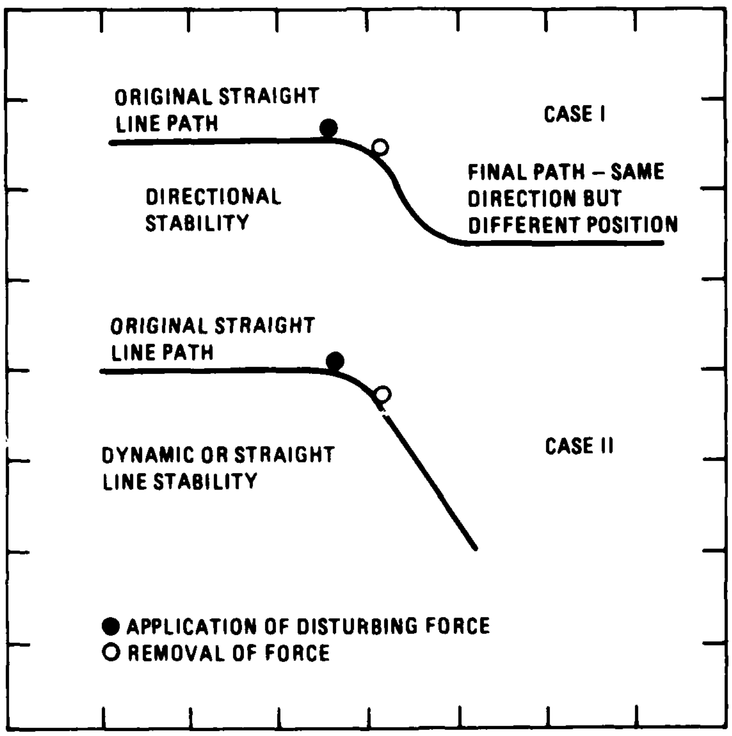

Figure 2.9. Comparison of Directional Stability and Dynamic Stability

The VEDB initially permitted simulator experiments to be conducted in the open sea or in New York Harbor. Additional areas are being continually added to the VEDB as required by specific experiments. To date, Valdez, Alaska, and Point Conception, California, have been added to the VEDB. The gaming area for most experiments consists of a 50 x 100 nm rectangle whose center can be fixed at any location on earth, but the area can be increased, if required, to 200 x 200 nm. Any orientation can be selected for the rectangle to fit the simulated area. The environment visible from areas of interest (channels, docking areas, etc.) are modeled in sufficient detail to be readily recognizable to mariners experienced in that area. The accuracy with which locations can be entered into the Image Generator data base is 1/40 of a foot; into the Situation Display data base, 24 feet; into the Radar data base, 35 feet. For New York Harbor the environments that were simulated were those visible from Ambrose Channel; the Narrows; Upper Bay; South of Constable Hook; Kill Van Kull; Newark Bay South Reach; Newark Bay Middle Reach up to Elizabeth Channel; and Elizabeth Channel. Geographical features, shorelines, and landmark structures visible from the foregoing areas are modeled. The following types of objects are modeled: water, terrain, aids to navigation, ownship's forebody, target ships, buildings, tanks,

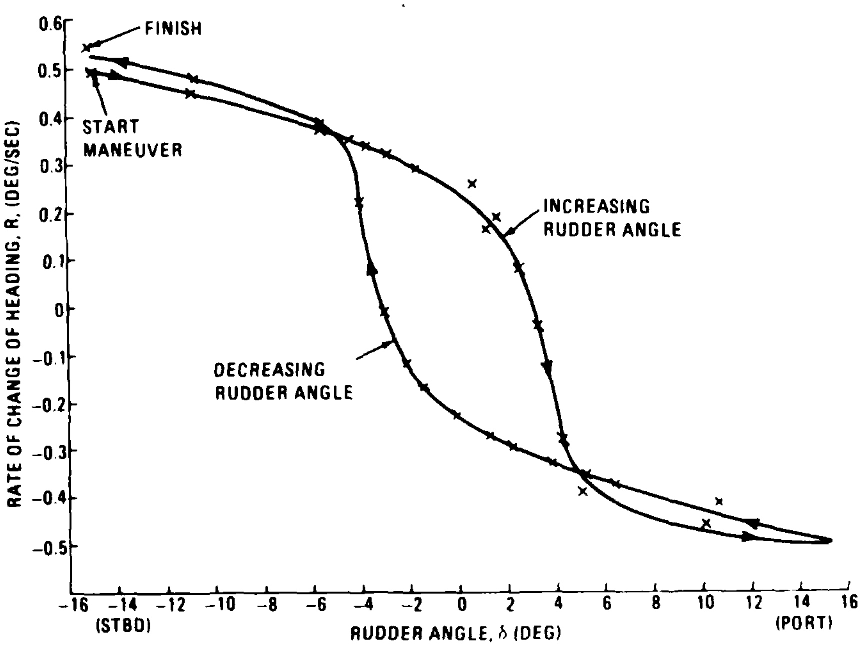

Figure 2.10. Spiral Maneuver - CAORF Ship

ships at anchor, bridges, cranes, derricks, and fog banks. As a result of open sea experiments, greater detail of traffic ships has been provided at increased ranges to aid in traffic recognition. The radar environment data base was developed from data representing the radar significant features within the gaming area. This gaming area is identical to the gaming area developed for the VEDB. All shoreline (with cultural and topographic features) within the radar range of ownship is modeled at a level of detail consistent with the resolution capability of the various radar ranges. The resolution of the radar data base in the fine data base is 35 feet; in medium data base, 140 feet; and in coarse data base, 280 feet. Ownship is free to move to the extent of the defined gaming area.

Table 2.1 presents a comparison of data for bearing and (where appropriate) range obtained from the visual display, the radar display, and nautical charts. The data indicate a

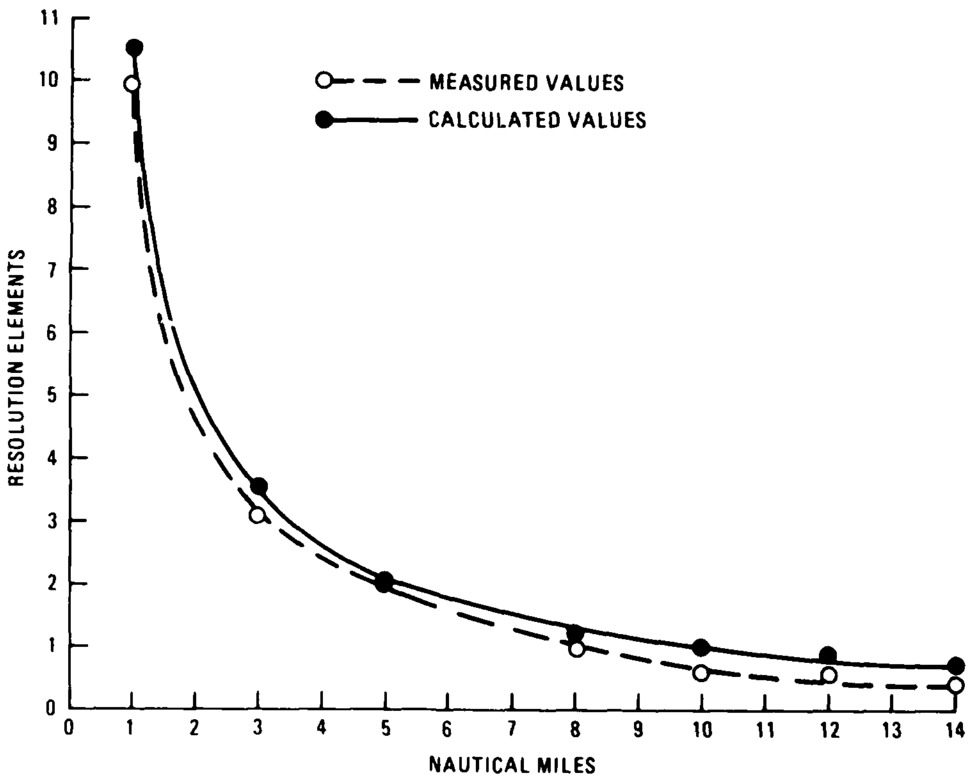

Figure 2.11. Horizontal Dimensions of Projected VLCC (Head-on) Versus Range

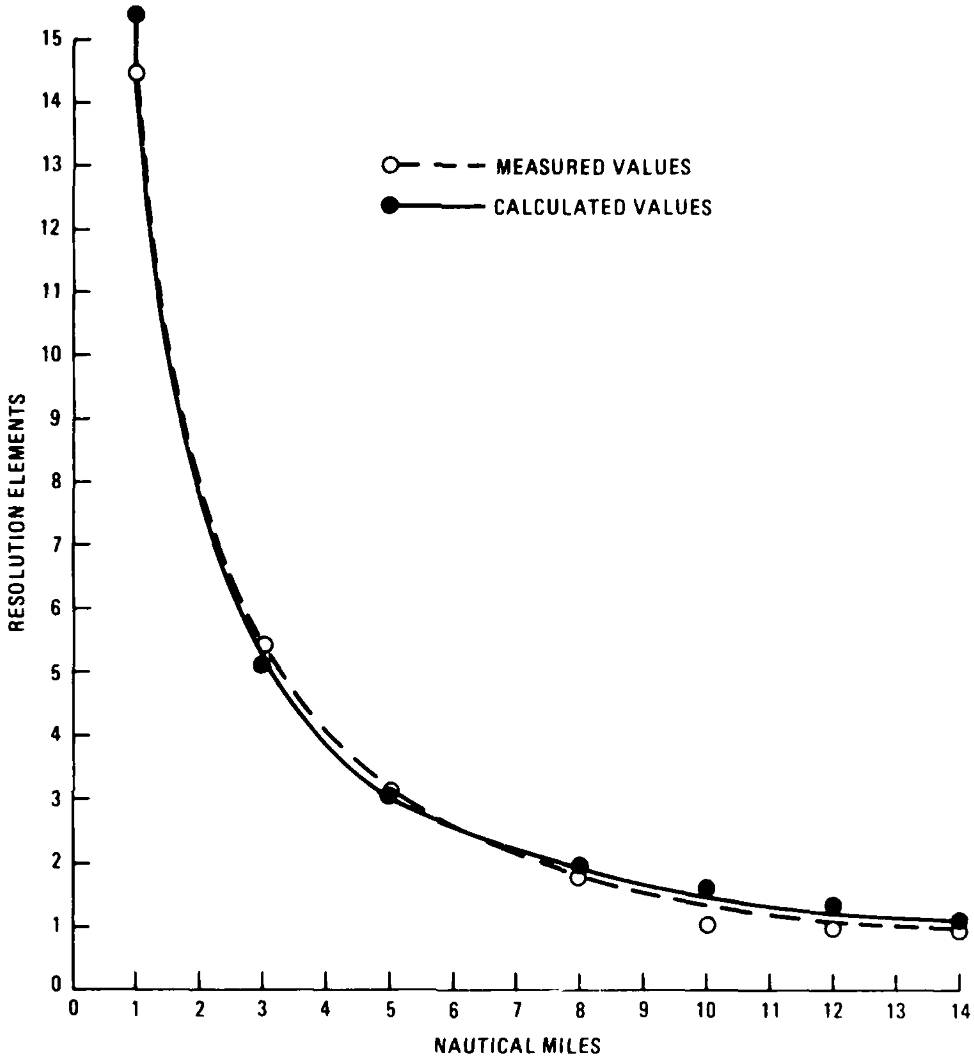

Figure 2.12. Vertical Dimensions of Projected VLCC (Head-on) Versus Range

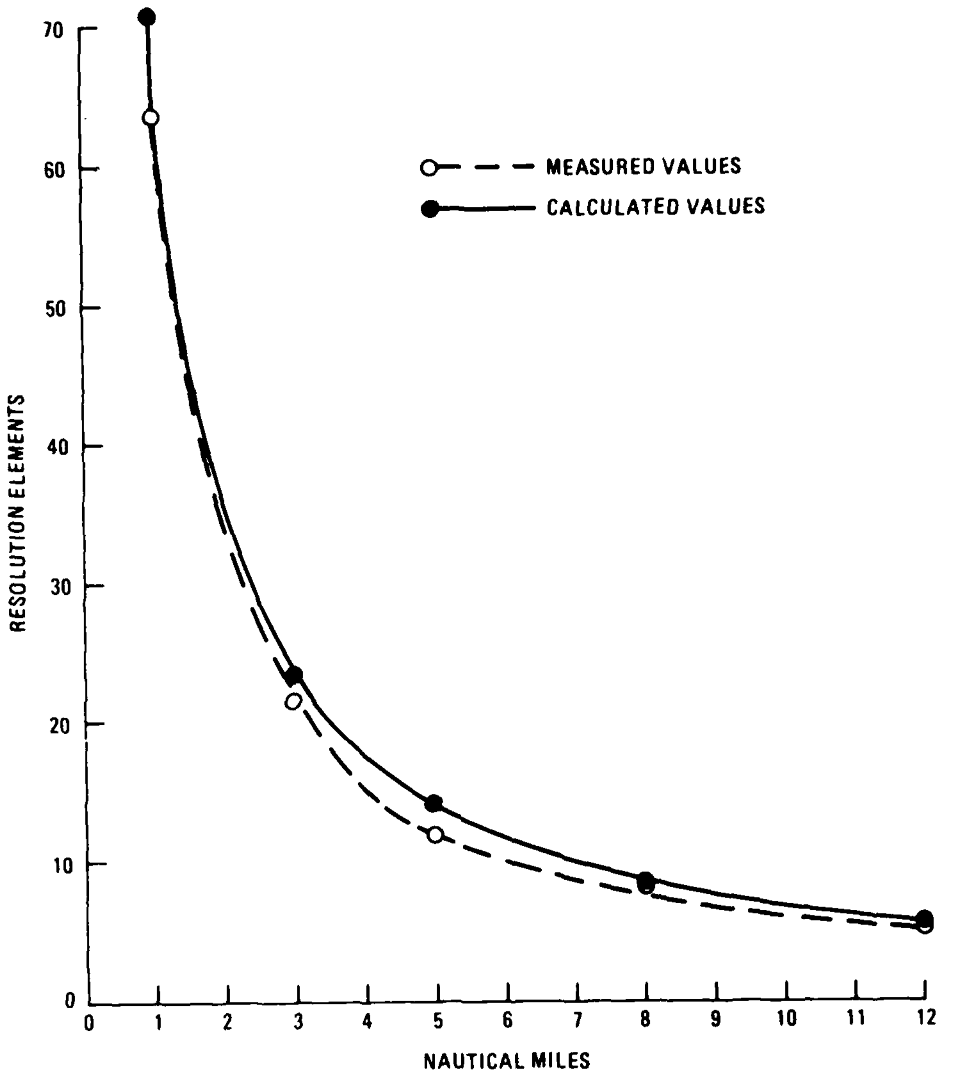

Figure 2.13. Horizontal Dimensions of Projected VLCC (Broadside) Versus Range

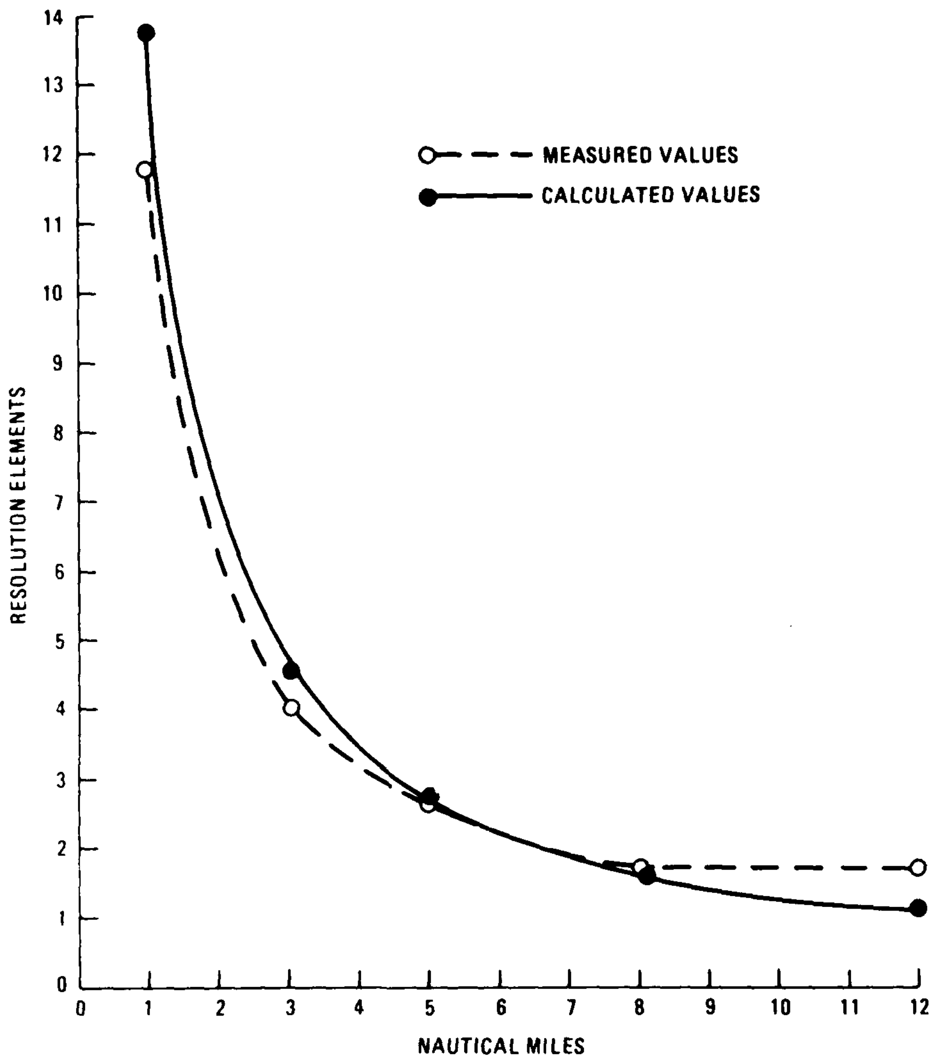

Figure 2.14. Vertical Dimensions of Projected VLCC (Broadside) Versus Range

high degree of data base correspondence. Slight discrepancies are present and are attributed to errors in data taking and difficulty in resolving bearing at close ranges.

Maps were digitized to prepare the situation display data base so that shorelines, channels, and buoys would be accurately displayed, enabling accurate position definition of ownship at the Control Station. No inconsistencies of significance have been noted with respect to the visual and radar data bases. The photographs in Figures 2.17 and 2.18 show the various presentations of the CAORF subsystems.

The radar and situation display pictures show the New York Harbor outline faithfully. The remaining pictures show various New York Harbor scenes and traffic ships generated

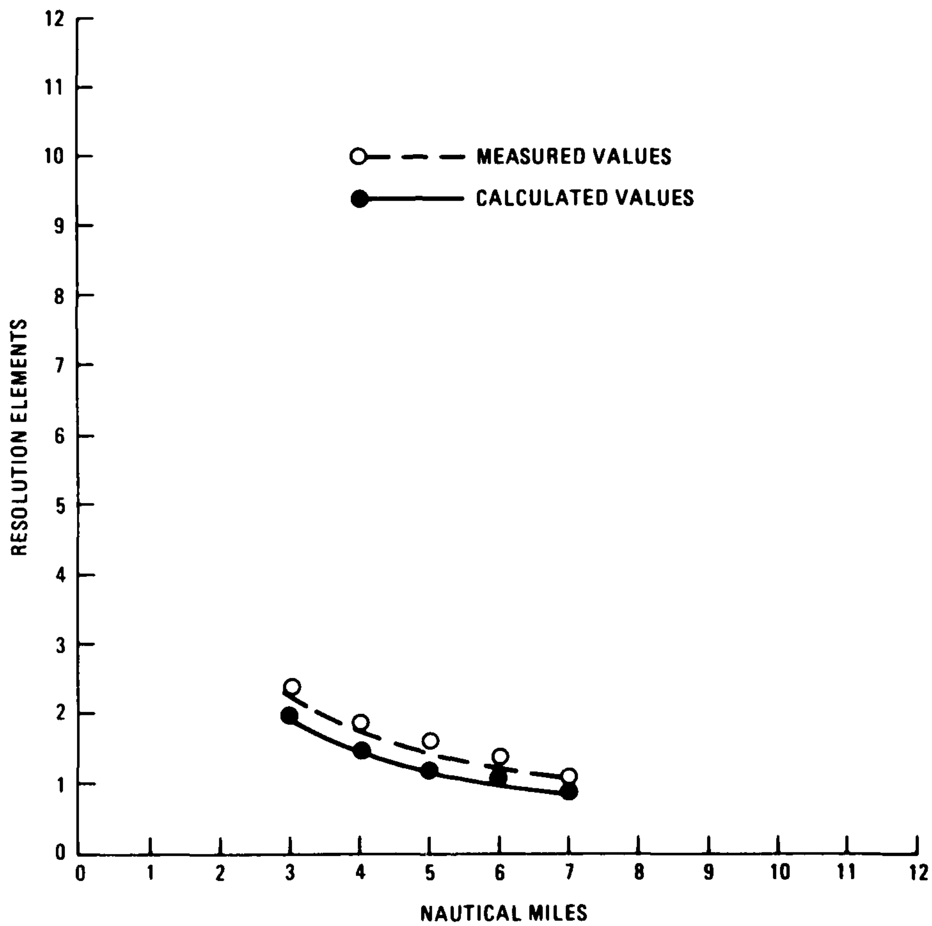

Figure 2.15. Horizontal Dimensions of Projected Cargo Ship (Head-on) Versus Range

by the VEDB. The latter data base has been critiqued and refined by Sandy Hook Pilots to include all visual cues required in the performance of their work.

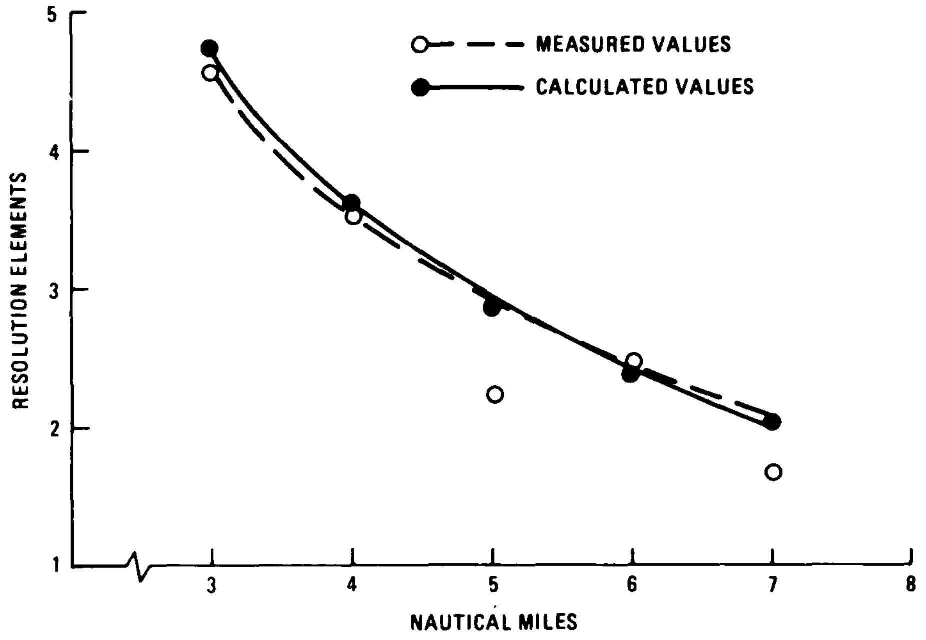

Figure 2.16. Vertical Dimensions of Projected Cargo Ship (Head-on) Versus Range

TABLE 2.1 VISUAL AND RADAR DATA BASES - BEARING AND RANGE DATA COMPARISONS

Object	Ownship True Heading	Visual Bearing		Radar Bearing		Radar Range (nm)	Chart	
		True	Rel	True	Rel		Bearing	Range (nm)
Ambrose	120°	121°7.2'	1°7.2'	120°30'	0°31'	2.67	120°	2.79
VNB Right Tower	315°	316°40'	1°40'	316°	1°	10.6	317°	10.3
Statue of Liberty	0°	3°	3°	2°45'	2°45'	2.42	5°45'	2.35
No. 3 Buoy	0°	87°	87°	87°30'	87°30'	0.46	98°31'	0.53

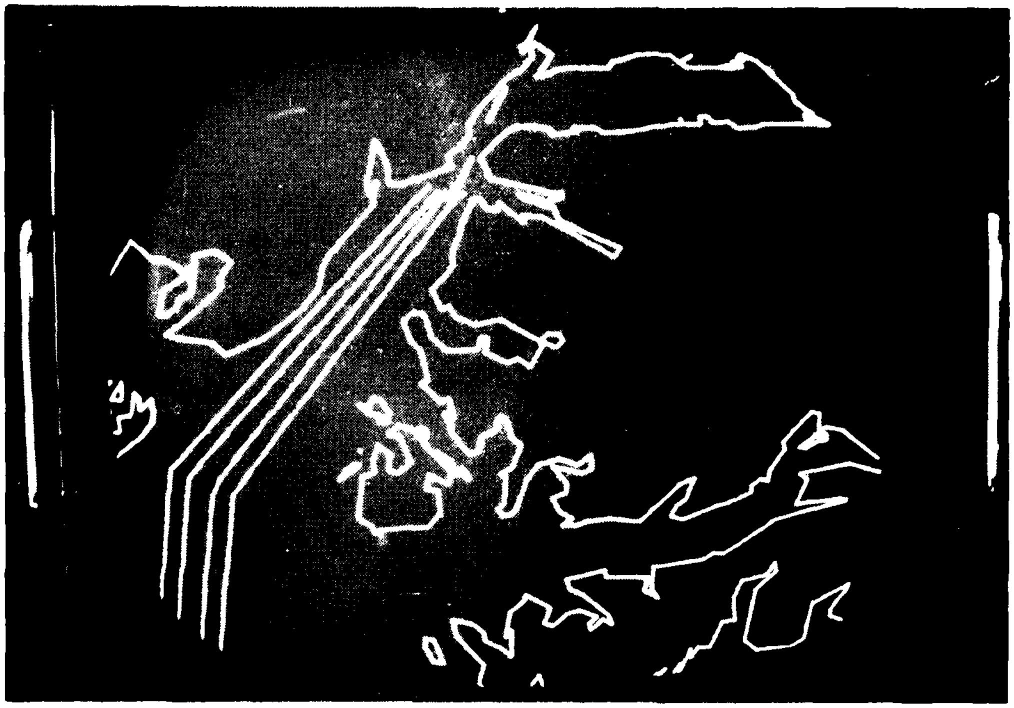

Figure 2.17. Typical Situation and Radar Data Base Displays

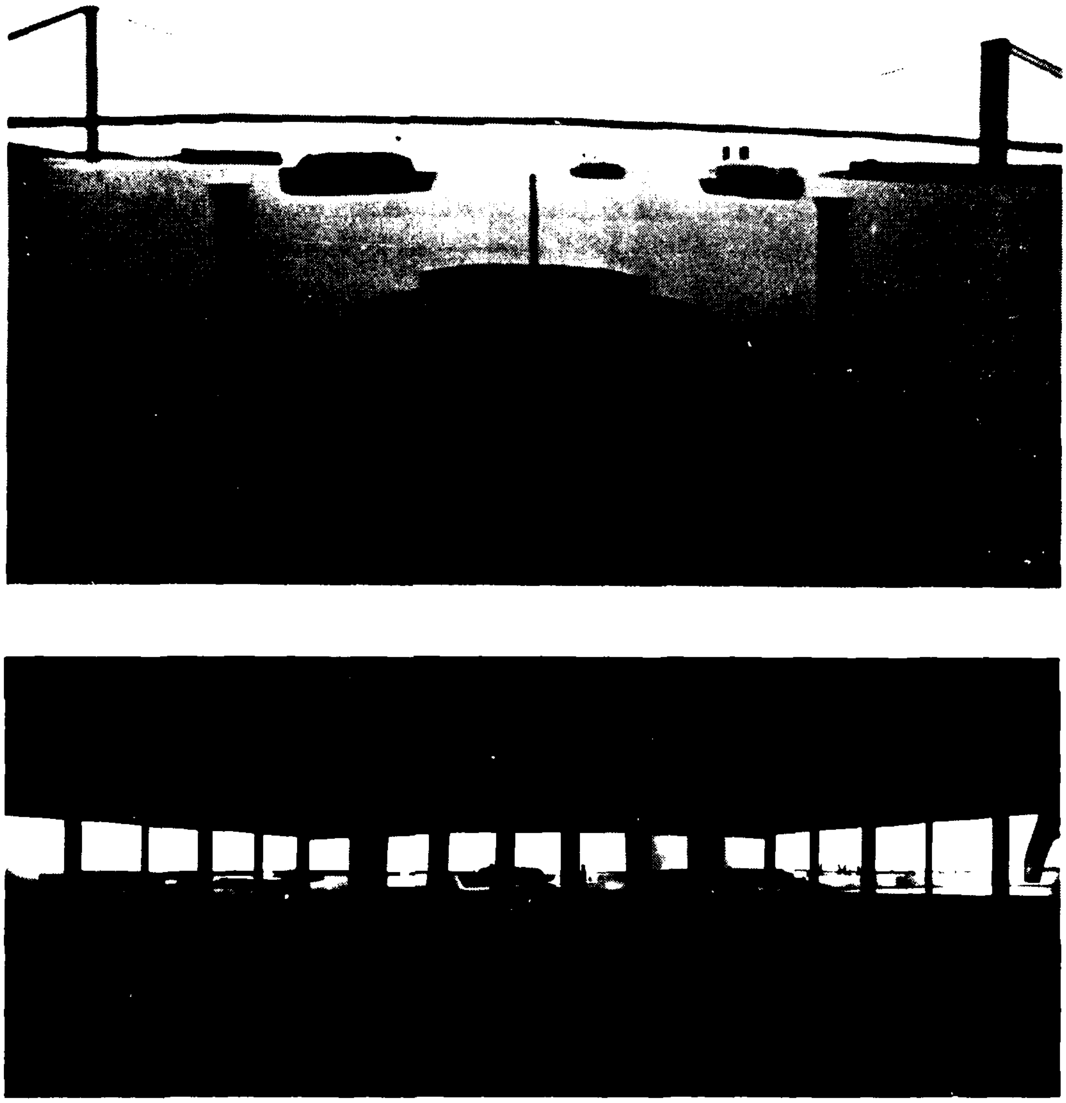

Figure 2.18. Typical Visual Data Base Displays

CHAPTER 3

VISUAL PERCEPTION VALIDATION

3.1 INTRODUCTION

Early in the validation program, two areas of concern arose relative to visual perception. The first dealt with the accuracy with which watch officers could estimate target ship distances from the visual presentation. The second related to the variability in the limited visibility characteristics of CAORF. The former is discussed in this chapter and the latter in Appendix B.

CAORF personnel obtained data on real-world range-estimation accuracy aboard a tanker. The watch officers were requested to estimate the distances of targets that were present, and these estimates were checked with radar. The results, as illustrated in Figures 3.1, 3.2, and 3.3 were excellent. Thus, to validate CAORF, range estimates on the CAORF bridge would likewise have to prove excellent. Following familiarization training of test subjects on CAORF, these results were obtained. With this precondition of familiarization training, visual perception validation is felt to have been accomplished. As an indication of the successful results, the differences between pre- and post-training results in estimation of target ship distances are discussed and illustrated in Figures 3.4 through 3.8.

Figure 3.4 compares actual programmed distances with estimates made at CAORF by experienced U.S. Merchant Marine Academy officers. The figure shows a tendency to over estimate at close ranges and underestimate at ranges greater than about 7 nautical miles.

Training was provided on the simulator to offset the tendency to overestimate distances at ranges between 0 and approximately 7 nautical miles. Test subjects are shown targets with different aspects and distances and asked to estimate their ranges (trial estimates). The trial estimates were recorded and the process repeated. The subjects were then shown another set of targets and were given their respective distances. After this, the first set of targets were again shown to the test subjects and their estimates of target ranges were again requested (trained estimates). The results for four test subjects are plotted in Figures 3.5 through 3.8.

For each subject, a regression line was plotted for each "trial" and "trained" set of data. The regression lines show an improvement in ability to estimate distance; the trained estimate regression line comes closer to the ideal line in three out of four cases. In the fourth case, the first trial estimates were so close to ideal that no training was needed.

The inability of test subjects to estimate distances accurately without training, in spite of the accuracy of the projected images, may result because the projected images are not as sharp on the screen as in the real world. Several test subjects commented about the haziness of the display. There is also empirical evidence to show that for

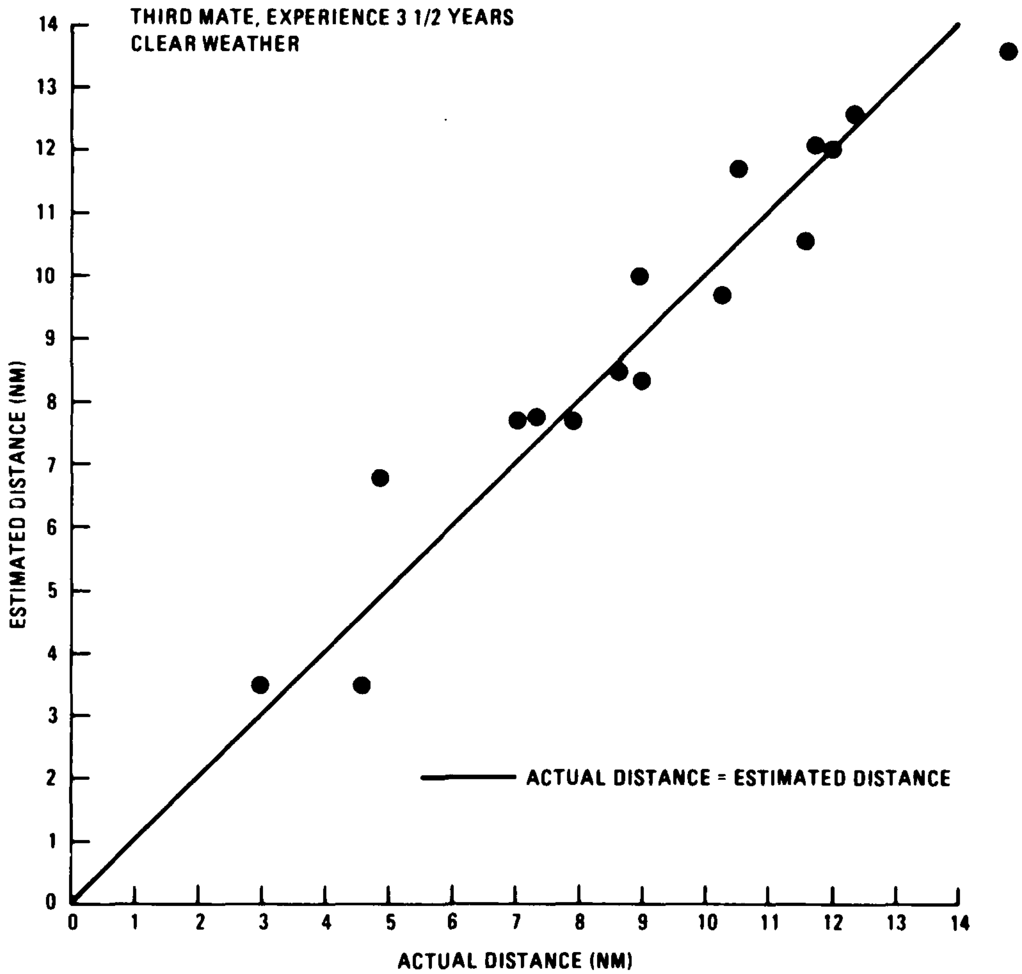

Figure 3.1. Watch Officer "E", Estimates of Range at Sea

an image to be realistic in a simulation, it must be shown approximately 1.3 times the expected size. For the present, it is felt that the training as described above suffices to eliminate the tendency to overestimate.

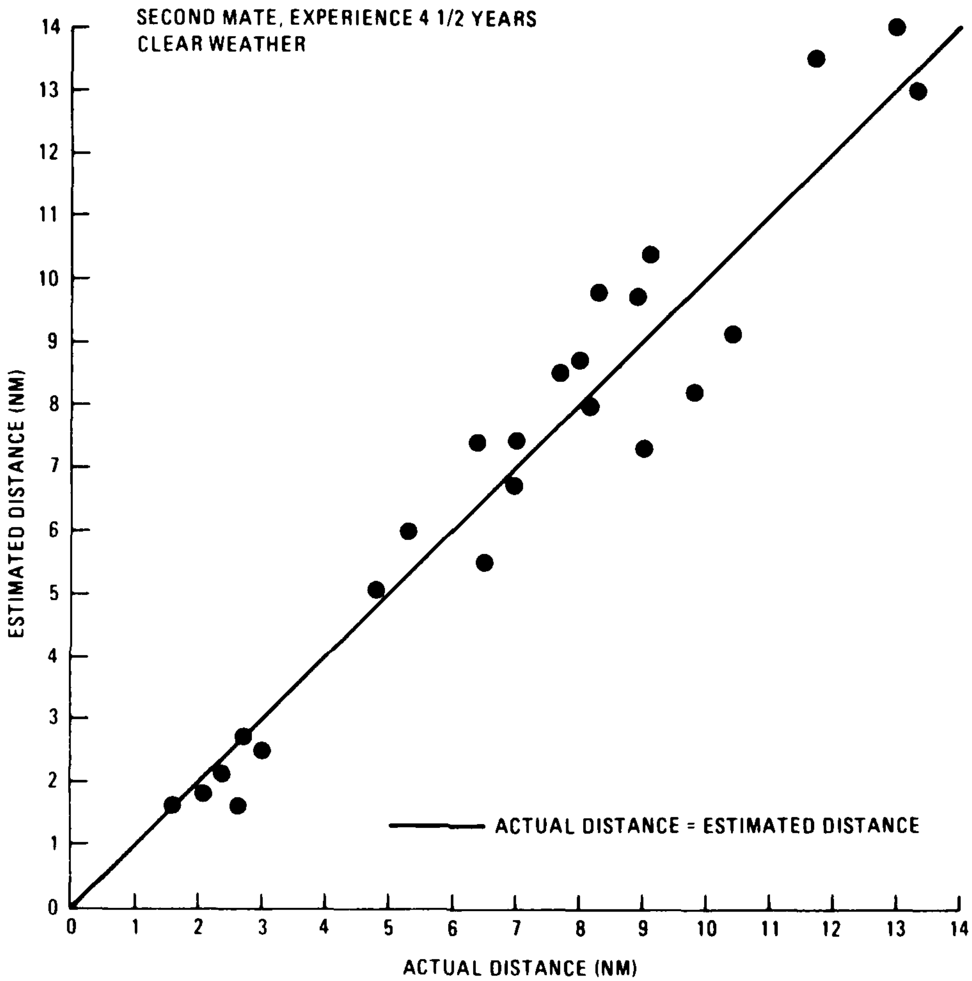

Figure 3.2. Watch Officer "F", Estimates of Range at Sea

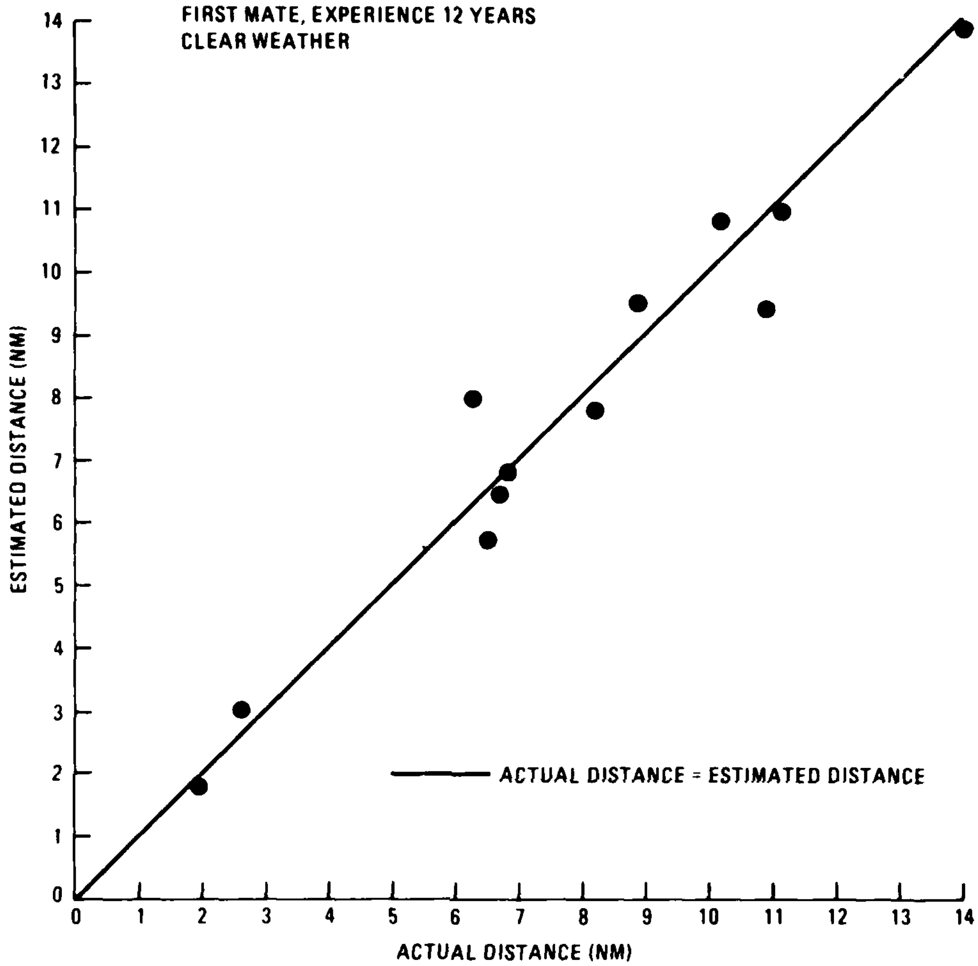

Figure 3.3. Watch Officer "G", Estimates of Range at Sea

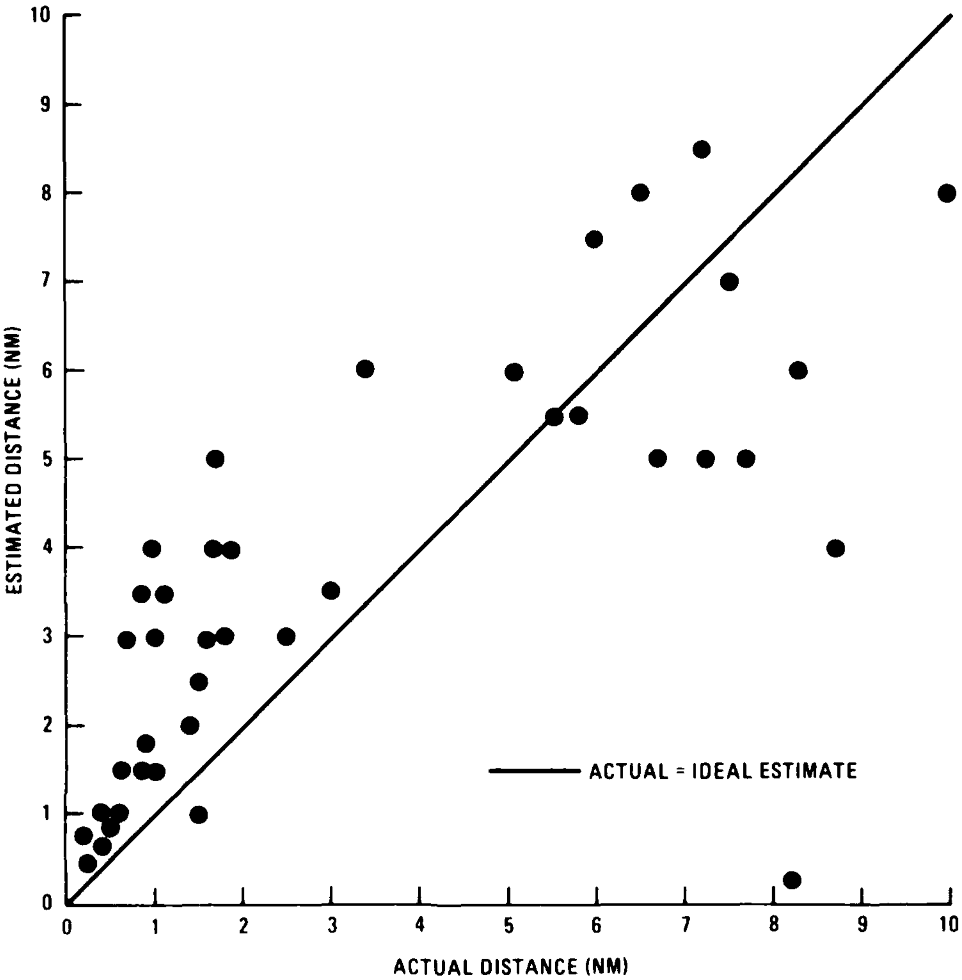

Figure 3.4. Estimates of Range from Visual Scene on CAORF - Pretraining

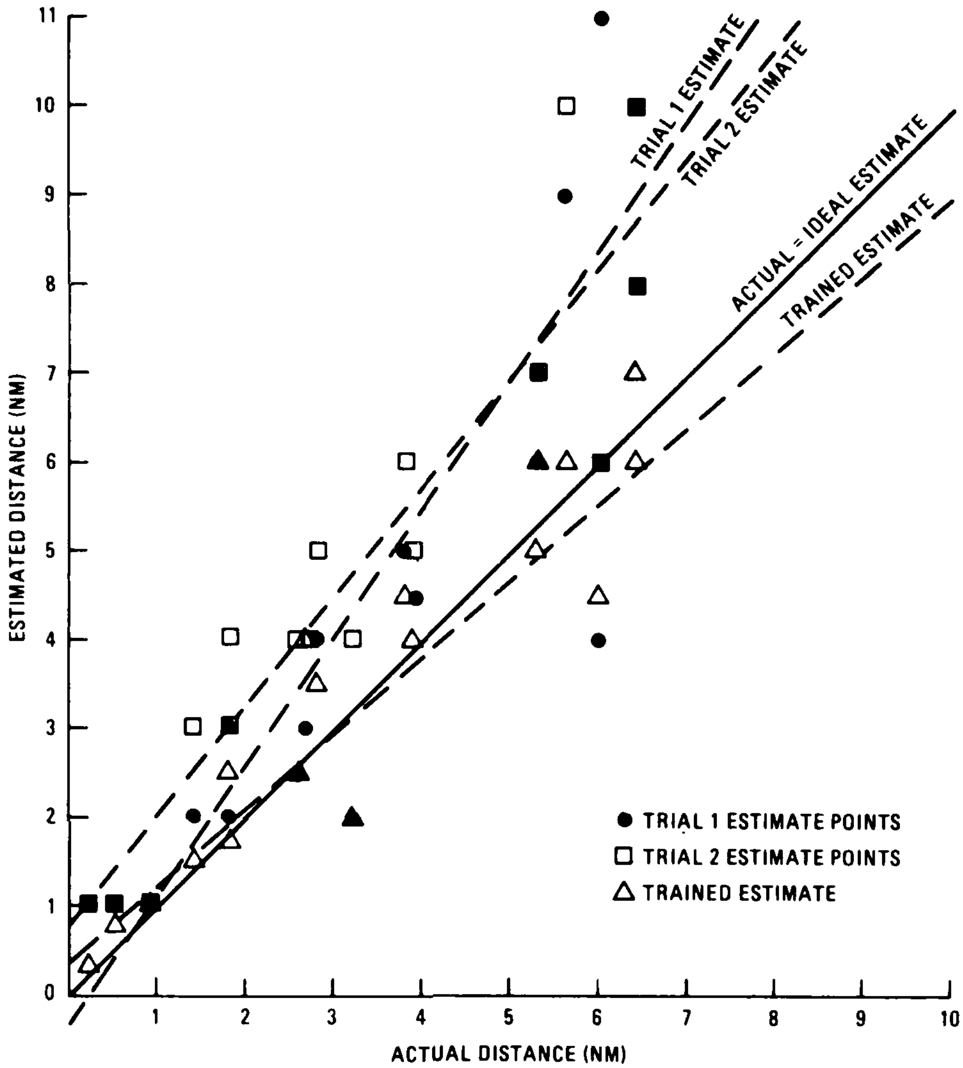

Figure 3.5. Test Subject "A", Estimates of Target Ship Range on CAORF, and Lines of Best Fit

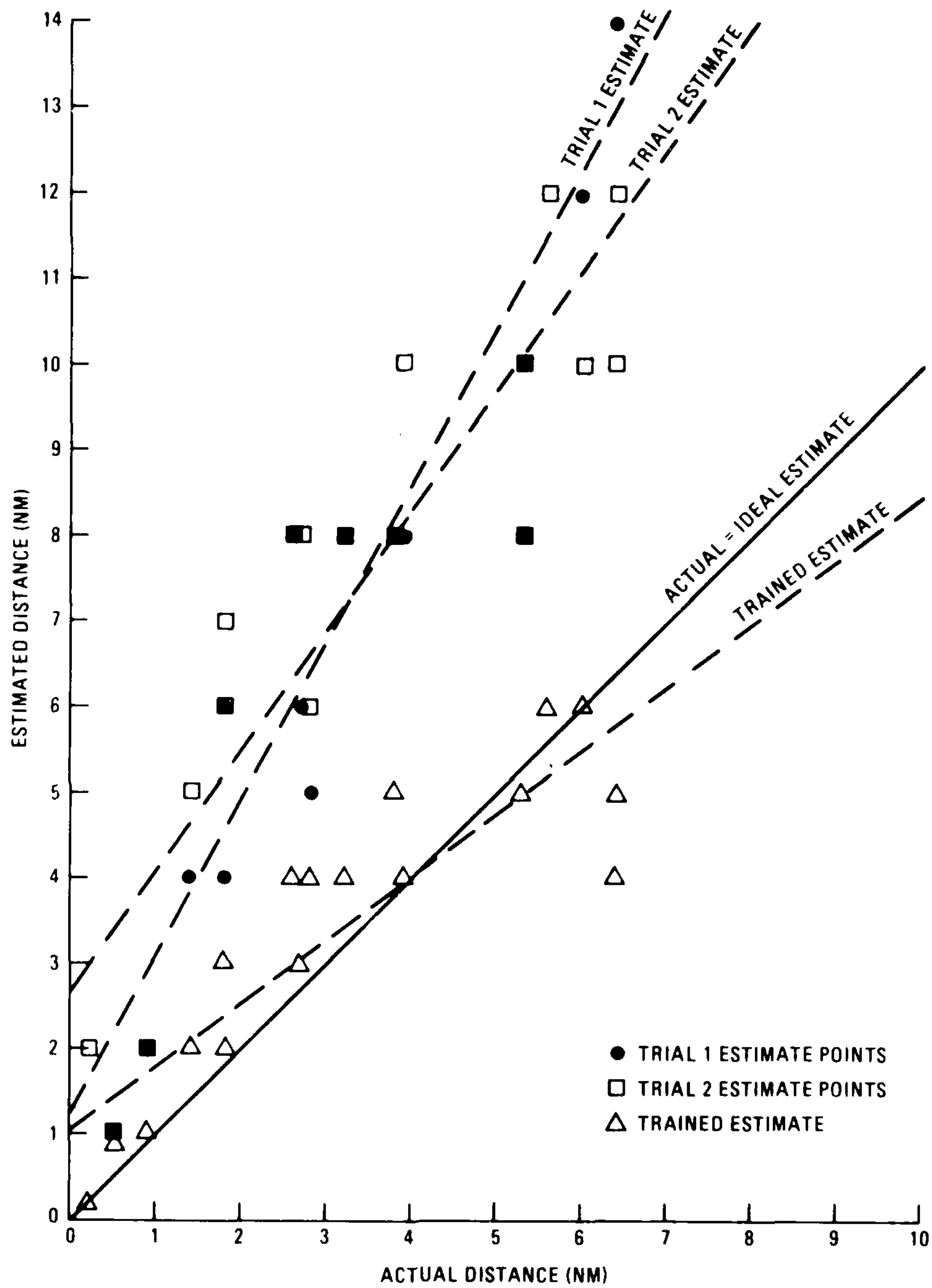

Figure 3.6. Test Subject "B", Estimates of Target Ship Range on CAORF, and Lines of Best Fit

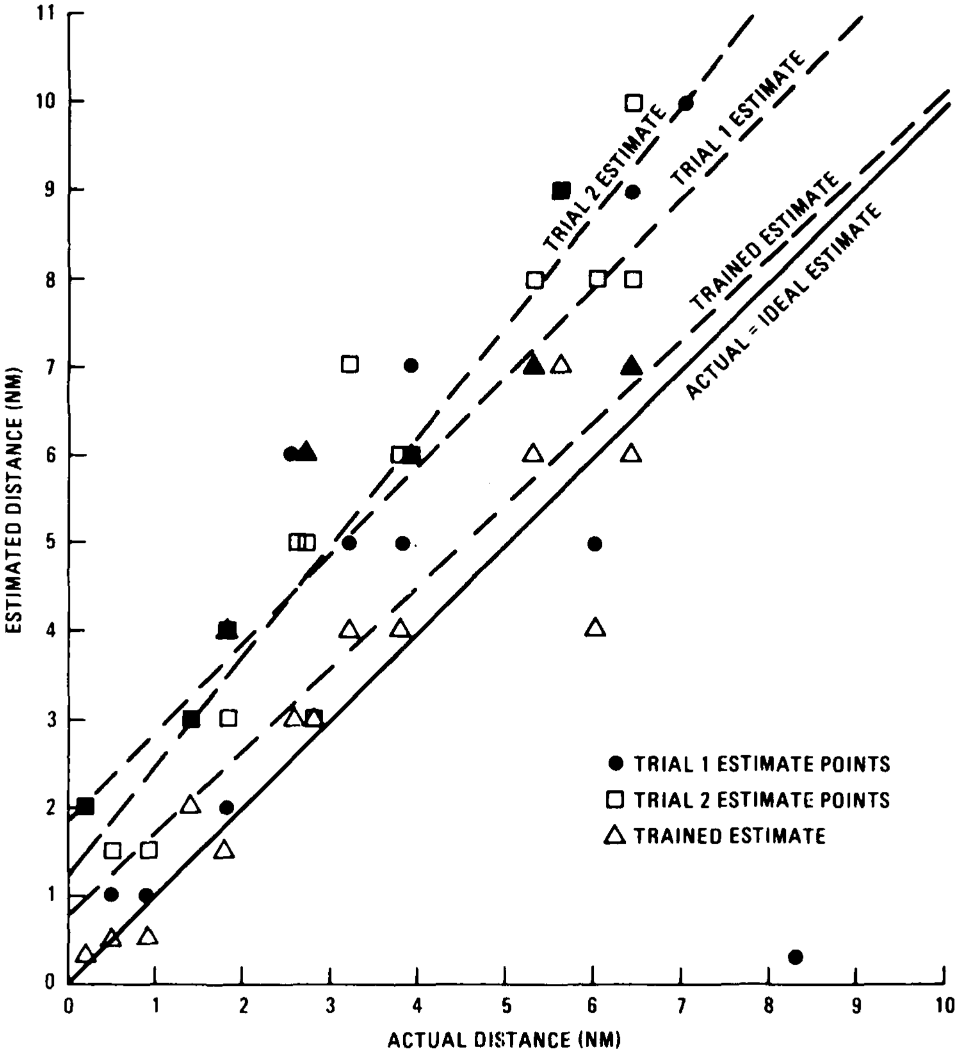

Figure 3.7. Test Subject "C", Estimates of Target Ship Range on CAORF, and Lines of Best Fit

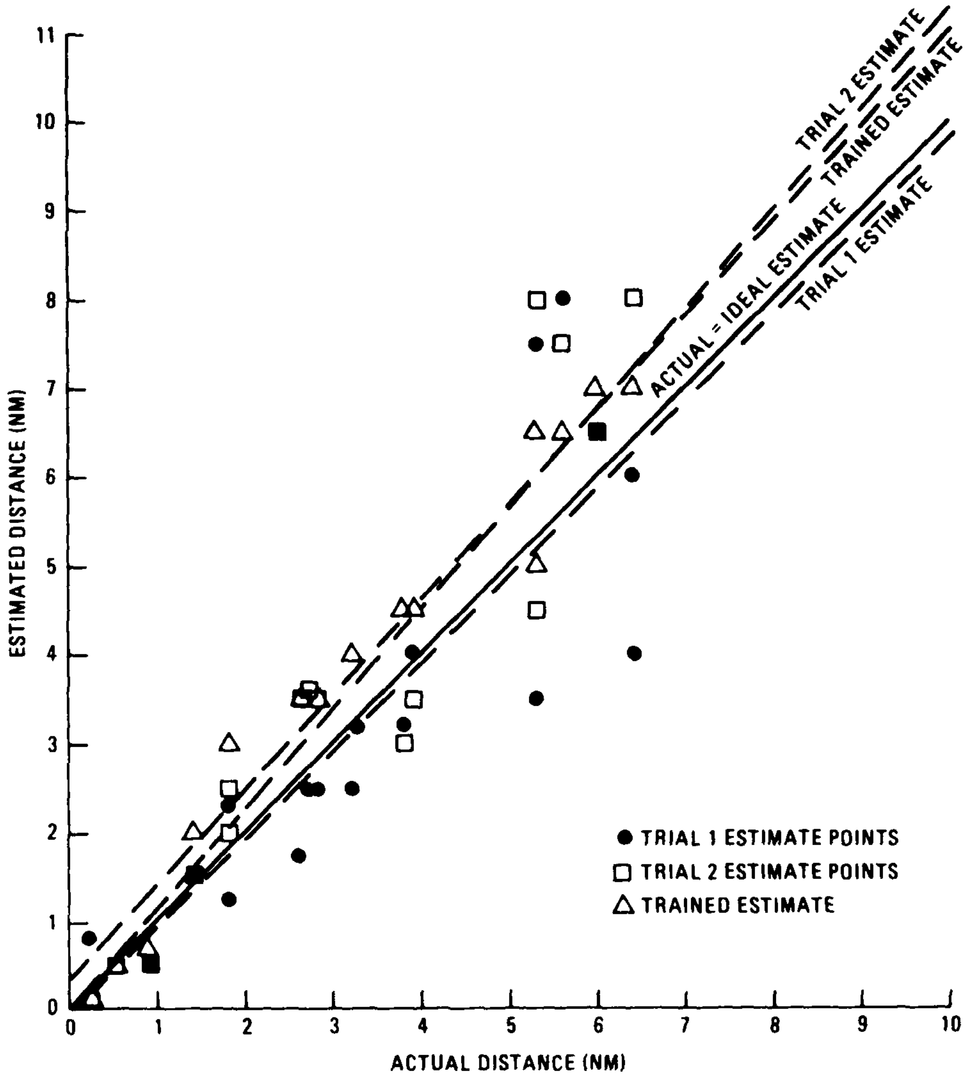

Figure 3.8. Test Subject "D", Estimates of Target Ship Range on CAORF, and Lines of Best Fit

CHAPTER 4

BEHAVIORAL VALIDATION

4.1 INTRODUCTION AND APPROACH

This section presents an overview of the findings resulting from the behavioral validation effort of CAORF. Only the predominant findings are presented in this overview. The interested reader is directed to Validation of Mate Behavior on the Computer Aided Operations Research Facility by Thomas J. Hammell, Eclectech Associates, Inc., to obtain specific details.

The area of behavioral validation was addressed by this empirical investigation. This area represents a summary of the effectiveness of the hardware validation and visual perception validation. It concerns the subject's adaptation to the limitations of the first two areas, and hence, the validity of empirical research to be conducted on CAORF. The project was tailored to investigate several predominant issues relating to the validity of empirical research to be conducted on CAORF. These were:

a. Mate's level of activity - Is the mate performing at a normal level of activity on CAORF, across different situations?

b. Mate's radar behavior - Is the radar function overemphasized on CAORF? Are the mates placing greater emphasis on radar when on the CAORF bridge?

c. Mate's distribution of tasks - Is the mate spending a proportionate effort across tasks on CAORF as compared with the real-world?

d. What is the extent of learning effects on CAORF?

e. How does the subject response variability on CAORF compare with that obtained at sea?

The approach that was followed to investigate behavioral validity centered around the comparison of mate behavior on CAORF with mate behavior at sea in similar situations. Mate behavioral data were compiled from trips at sea during a study regarding Standardized Bridge Design conducted for the Office of Advanced Ship Operations. These data were assembled into a computer data base to be used for analysis purposes. Three four-hour watch scenarios were constructed from actual at-sea situations. These scenarios represented a variety of conditions (e.g., low and high contact loads; limited and unlimited visibility; restricted waters and open

sea). A group of mates (subjects) were individually run on the CAORF bridge in each of the four-hour watch scenarios. Behavioral data were collected during these CAORF runs, using data collection techniques similar to those employed at-sea.

The analysis compared mate behavior on CAORF and at-sea, using a variety of behavioral measures. The behavioral data were segmented and analyzed in terms of two separate configurations, enabling a comprehensive investigation of mate behavior. These configurations were:

a. Within scenario analysis - CAORF data collected during specific scenarios were compared to the at-sea data collected during the respective time segments. This was a one-to-one comparison of each scenario with its respective at-sea segment. The behavior occurring on CAORF over time was directly related to that occurring during the similarly evolving situation at sea. The major limitation of this analysis is the sample size of one mate for each at-sea data segment.

b. Between segment analysis - The CAORF scenarios were partitioned into segments on the basis of the mate loading dimension (learning period, low and high contact loads), and the environment dimension (open sea and restricted waters/limited visibility conditions). In this manner, behavior on CAORF was compared with behavior in many similar at-sea situations.

The analyses investigated four task categories: 1) all tasks, 2) radar tasks, 3) navigation tasks, and 4) other tasks. The All Tasks category is the summation of the other three categories. This breakdown allowed the investigation of specific issues of concern, while yielding sufficient CAORF data to achieve meaningful results.

A secondary validation analysis was conducted on ship performance - Closest Point of Approach (CPA) range, target range when ownship initiated a maneuver, and the percentage of contacts allowed within a one-mile CPA. This analysis similarly compared CAORF performance with at-sea performance. The CAORF data used for this investigation were obtained from the initial pilot experiment on CAORF, rather than the validation runs.

4.2 FINDINGS

Mate behavior on CAORF was found to be similar in many respects to mate behavior in corresponding situations at-sea, generally indicating satisfactory CAORF validity. The changes in mate behavior as a function of situation characteristics agreed well with the corresponding at-sea behavior. The primary difference between CAORF and at-sea mate behavior was a higher level of activity on CAORF. Mates on CAORF generally worked at an average level of activity equivalent to that observed in the most difficult situations at sea. Further investigation showed that the enhanced level of activity was due to a significant learning effect, perhaps similar to that encountered when a mate takes the watch on board an unfamiliar ship. The mates on CAORF had relatively little experience on that bridge prior to the validation runs. This learning effect was observed to subside as the mates gained experience on CAORF, with their level of activity decreasing to that observed at-sea.

An overall comparision between CAORF and at-sea behavior is shown in Table 4.1, listing workload (percentage of total time devoted to particular tasks) as a function of task categories and situation conditions. An average correlation value of $T = 0.6$ (Spearman Rank Correlation Coefficient) was obtained for these data. A high correlation value of $T = 0.9$ was obtained for these data with the navigation task category removed. A probable reason for the low navigation correlation is discussed below. Of interest is the high correlation obtained between the CAORF and at-sea data regarding the All Tasks and Radar categories, demonstrating the similarity of behavior. Also evident from this summary table is the enhanced level of mate behavior on CAORF due to the learning effect. Specific findings are addressed below regarding:

a. The learning effect.
b. Radar.
c. Navigation.
d. Ship performance.

4.2.1 Learning Effect

The behavior of mates on CAORF demonstrated trends similar to the behavior of mates at-sea; the mate level of activity on CAORF was, however, considerably higher. The average mate workload during the four-hour watch of Scenario #2 (Matanilla Shoals) demonstrates this relationship (see Figure 4.1). The average workloads for all tasks, radar task, and navigation task categories are shown to change in

fifteen-minute intervals across this watch. The corresponding contact load for this watch is shown in Figure 4.2 (see the full report text for an explanation of the contact load parameter).

Comparison of these two figures shows the following:

a. A high level of activity occurred during the first hour or so, when the contact load was zero - this was attributed to a pronounced short-term learning effect that lasted for about the first hour of the mate's initial watch on the CAORF bridge.

TABLE 4.1. OVERALL CAORF AND AT-SEA WORKLOAD DATA COMPARISON

Task	Sea Condition/ Contact Load	Workload (%)	
		CAORF	At-Sea
ALL TASKS	OPEN SEA/LOW	27.0	1.56
	OPEN SEA/HIGH	48.2	32.60
	RESTRICTED WATERS/ LIMITED VISIBILITY	47.6	54.00
RADAR	OPEN SEA/LOW	12.0	6.00
	OPEN SEA/HIGH	34.4	20.00
	RESTRICTED WATERS/ LIMITED VISIBILITY	30.0	22.00*
NAVIGATION	OPEN SEA	11.4	9.60
	RESTRICTED WATERS/ LIMITED VISIBILITY	7.5	22.05*

SPEARMAN RANK CORRELATION COEFFICIENT

T = 0.6 ($p < 0.075$) OVERALL

T = 0.9 ($p < 0.05$) WITHOUT NAVIGATION

*These at-sea data pertained to 2 watchstanders on the bridge during those periods. The correction factor was a division by 2 to yield the data in the respective cells.

b. The small increase in contact load around time 0900 was met with a corresponding increase in the mate's navigation workload - ownship passed a buoy near this time.

c. The large increase in contact load near the end of the watch was met with a large increase in the mate's radar activity - a difficult situation with several close contacts encountered.

Hence, the mate's workload on CAORF changed in accordance with the situation. The actual mate's workload at-sea in this situation is shown in Figure 4.3. Comparison of the CAORF and at-sea workload curves show the correspondence between the at-sea navigation workload increase around time 0900, and the radar workload increase near the end of the watch. Although the relative differences across the scenario were similar on CAORF and at-sea, the CAORF workload was consistently higher. It is suggested that this result was due to the learning effect.

The learning effect on CAORF may be caused by any of the following factors:

a. The mate's lack of knowledge concerning CAORF and its objectives.

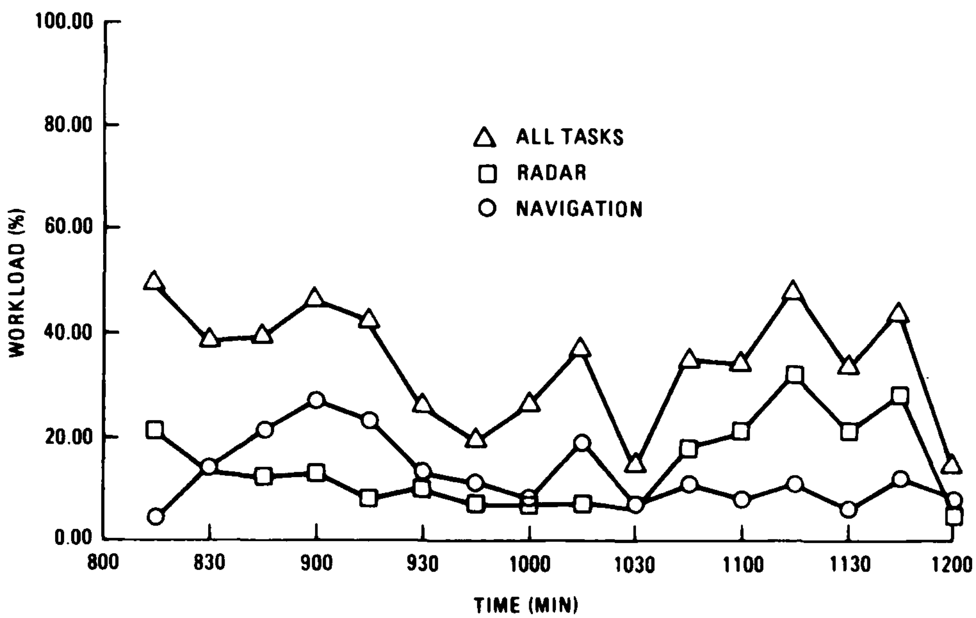

Figure 4.1. CAORF Average Workload Versus Scenario Time - Matanilla Shoals, Scenario 2

b. The mate's unfamiliarity with the CAORF facility and personnel.

c. The mate's unfamiliarity with the CAORF bridge equipment, layout, and procedures.

d. The mate's unfamiliarity with aspects of the simulation.

e. Performing in front of a group of people, directly or indirectly.

f. The prospect of having his performance monitored and analyzed.

g. The nature of the experiment itself.

This list is by no means exhaustive; these factors are only some of which may contribute to the learning effect on CAORF. The existence of a long-term learning effect, and its eventual cessation, are demonstrated by the workload of one mate who was on watch twice in Scenario #2. The first time on watch was similar to that for the other mates; his second watch in this scenario occurred two months later, after he had some additional experience on CAORF. More

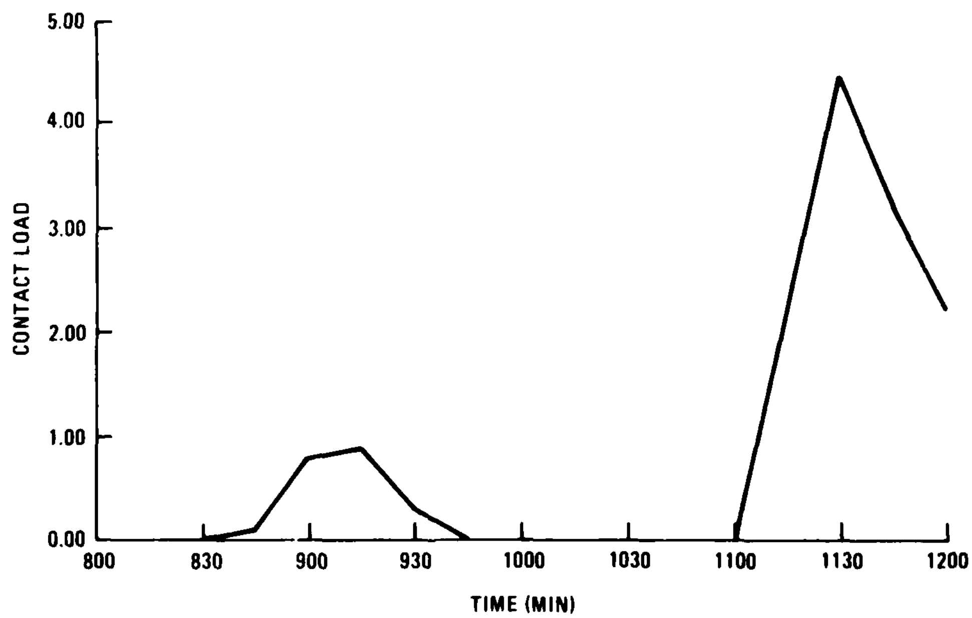

Figure 4.2. Contact Load Versus Scenario Time Matanilla Shoals, Scenario 2

essence, his CAORF behavior becomes more like at-sea behavior as he settles down and gains experience with CAORF. Additional findings further substantiating the learning effect are discussed in the text of the full report.

The learning effect should not present a major obstacle. The analysis showed that CAORF and at-sea behavior were similar in difficult situations (i.e., restricted waters/ limited visibility with a high contact load).

4.2.2 Radar

The CAORF radar behavior was found to agree well with the at-sea behavior when the learning effect is taken into account. The following points summarize these findings:

a. Mates had a higher level of radar activity on CAORF than at-sea. The higher radar activity, however, coincides with higher activity on all tasks. The increased CAORF radar activity is, therefore attributed to the learning effect.

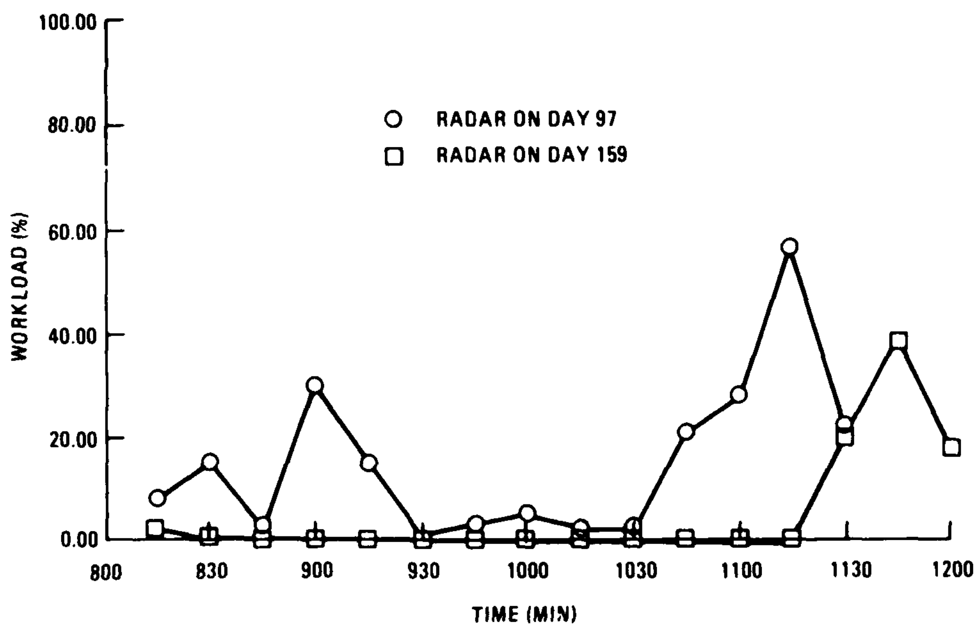

Figure 4.4. Long-Term Learning Effect on Radar Behavior - Workload Versus Scenario Time, Matanilla Shoals, Scenario 2

b. The CAORF radar workload was found to change directly with the contact load, in a manner similar to at-sea behavior.

c. Significant differences in time per task exist between the CAORF low and high contact loads. These findings are indicative of different types of radar behavior in the low and high contact load situations on CAORF, namely search/detection and analysis behavior, respectively.

d. The mates on CAORF anticipated imminent problems during their watch, as indicated by the relatively high number of search/detection radar tasks (i.e., short duration radar tasks).

4.2.3 Navigation

The CAORF navigation behavior differed from at-sea navigation behavior in several respects (see Figure 4.5). First, whereas the at-sea navigation workload increased with the contact load, the CAORF navigation workload decreased. This difference probably reflects the experimental emphasis that was placed on collision avoidance performance. A contributory factor to this difference is the observation that the CAORF mates were generally working at their maximum level during the watch. When the contact load was increased, thereby requiring more radar attention, the mate reduced his navigation workload to compensate for the necessary increase in his radar workload. This rationale also applied to trend differences observed between the CAORF and at-sea navigation task frequency curves.

The second major difference between the CAORF and at-sea data was in the average time per navigation task. This difference reflects the relative speed and ease with which CAORF fixes were obtained during the validation runs. The average CAORF navigation tasks were performed significantly faster than the at-sea tasks and the difference is statistically supportable (Rank Sum Critical Values Test: $p < 0.01$ (4,8)). The CAORF procedure definitely required much less time to obtain the LORAN or DECCA fix.

The navigation findings are summarized by the following:

a. The trends in CAORF and at-sea navigation behavior were found to differ across the contact loads. These differences were attributed to the relatively high emphasis placed on collision avoidance behavior during the CAORF runs, and the lack of adequate CAORF navigation equipment at the time of the validation runs.

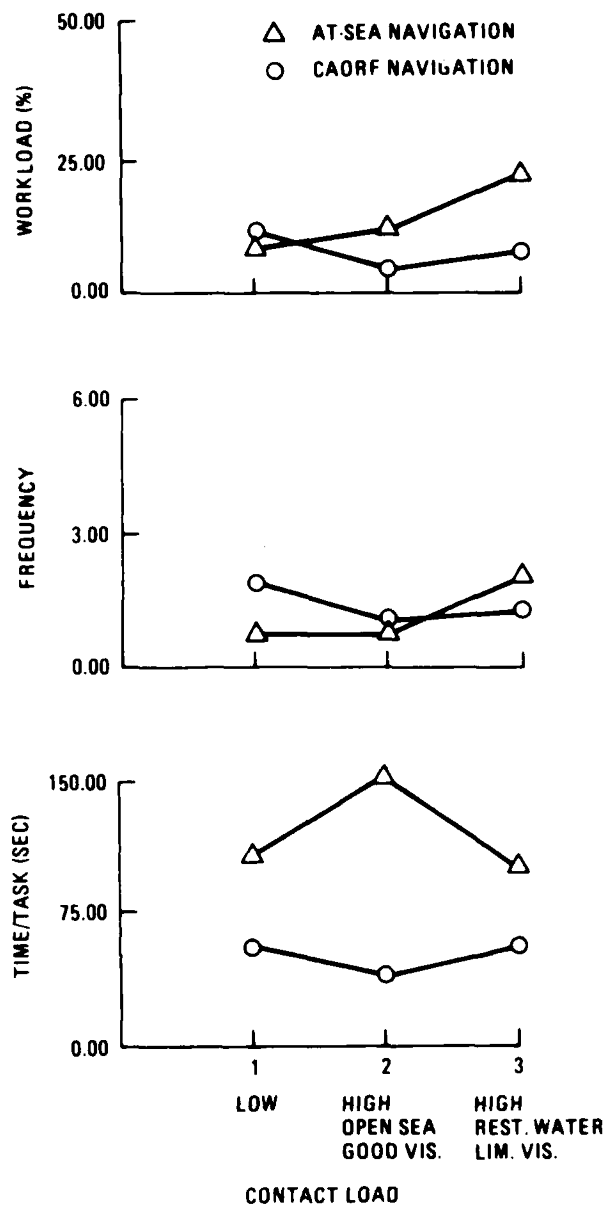

Figure 4.5. Navigation Behavior as a Function of Contact Load

b. Large differences in the average time duration of navigation tasks were found between the CAORF and at-sea data. The significantly faster navigation tasks on CAORF were due to the manual method of providing fix information to the mate.

c. The differences between CAORF and at-sea navigation behavior may be easily rectified by appropriate experimental procedures, and installation of navigation equipment and simulation characteristics.

4.2.4 Ship Performance

CAORF and at-sea ship performance demonstrated similar differences between traditional and automated (i.e., having a collision avoidance system) bridges. In this regard, empirical research on CAORF would have yielded effects similar to those occurring at-sea. CAORF and at-sea ship performance, however, differed with regard to the magnitude of the respective parameters. CAORF performance showed cautiousness by the mates, exhibiting symptoms of the learning effect shown regarding mate behavior.

The almost constant differences in CPA range between CAORF and at-sea performance for traditional and automated bridges are shown in Figure 4.6. A nearly constant offset of 0.3 nm across both bridge configurations was obtained between CAORF and at-sea CPA range.

The range at which ownship maneuvered demonstrated cautiousness by CAORF mates (Figures 4.6 and 4.7). CAORF performance was nearly identical to at-sea performance on the traditional bridge indicating that ownship may have maneuvered as soon as appropriate information was obtained regarding the situation. The collision avoidance system provides the capability to rapidly ascertain the necessary target information long before the maneuver should be made. The mates at-sea and on CAORF both took advantage of the CAS capabilities, maneuvering their respective ships earlier than those with the traditional bridge. The CAORF mates, however, demonstrated cautious behavior by maneuvering their ship considerably earlier than occurred in the at-sea situation.

The ship performance data demonstrates definitely similar trends between CAORF and at-sea situations, across traditional and automated bridges. This is true even though no attempt was made to control for the situation differences between these CAORF and at-sea data. The differences between the CAORF and at-sea data were generally attributed

to cautiousness by the mates, or the experimenter's instructions. Again, these findings support the quality of the CAORF simulation.

4.3 CONCLUSIONS

The findings from the Mate Behavior Validation effort demonstrate a high degree of similarity between mate behavior on CAORF and at-sea. Mates were generally much more active on CAORF than at sea; the relative behavior differences, however, were nearly identical between the CAORF and at-sea situation. The increased activity on CAORF of all tasks is attributed to a learning effect, resulting in a maximum level of mate activity. The learning effect was observed to subside over time.

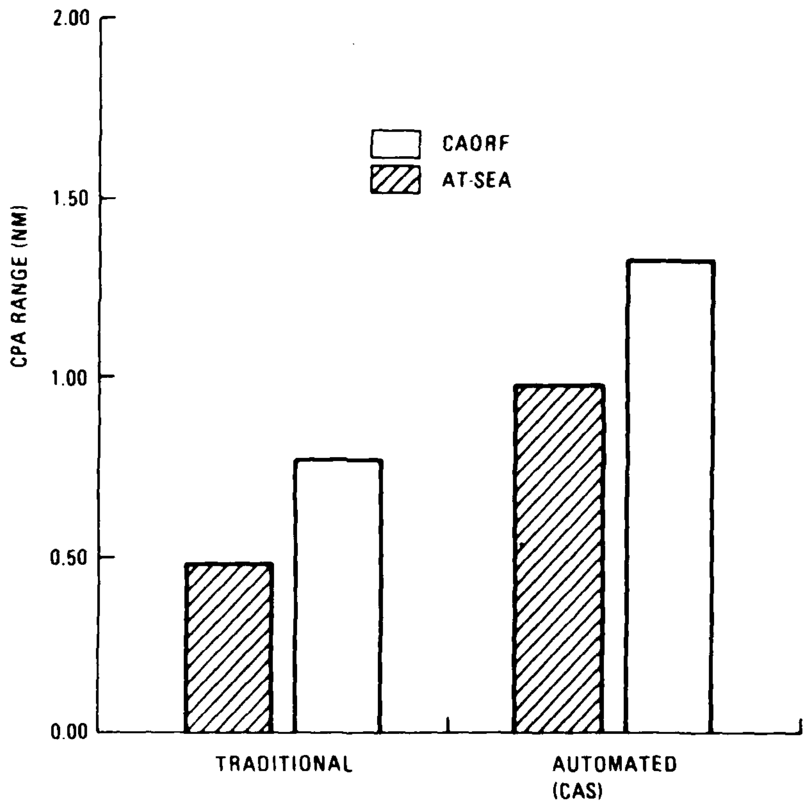

Figure 4.6. CPA Range for Traditional and Automated Bridges - CAORF and At-Sea

The specific conclusions are listed below:

a. Mate behavioral data collected on CAORF were similar to those collected at-sea, demonstrating wide variances between mates.

b. Good agreement was obtained between mate behavior on CAORF and at-sea, demonstrating a strong relationship between the at-sea situation and its CAORF simulation.

c. Mate behavior on CAORF changed in direct accordance with the situation conditions (e.g., contact load) similar to behavior observed at-sea.

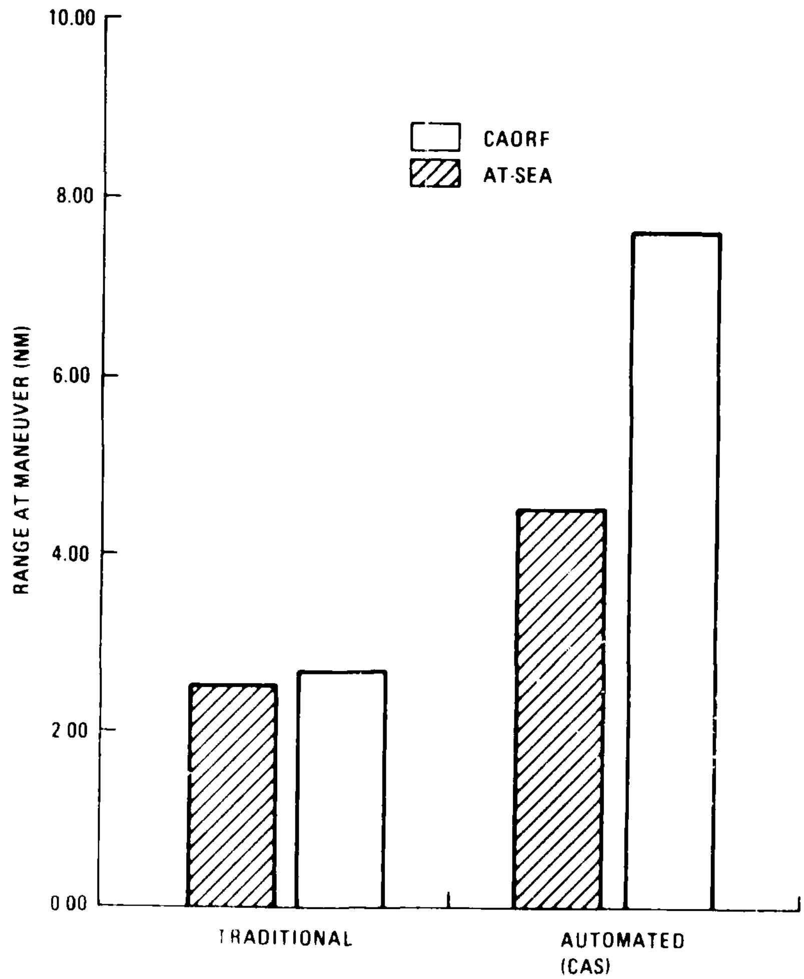

Figure 4.7. Range of Maneuver, Traditional and Automated Bridges - CAORF and At-Sea

d. Mate activity on CAORF was generally at a much higher level than the corresponding at-sea activity. This was generally true for all tasks, radar tasks, and navigation tasks. This was attributed to a strong learning effect. Nevertheless, the behavioral trends were nearly identical between CAORF and at-sea data.

e. CAORF mates were generally working at a maximum level as if in a difficult situation. Their behavior was most similar to at-sea behavior in difficult situations such as restricted waters/limited visibility/high contact load. Their activity level was considerably greater than at-sea activity in the less difficult situations. Hence, CAORF mates apparently perceived most situations as difficult; this may be attributed to their relative unfamiliarity with CAORF and the experimental situation, i.e., the learning effect.

f. A strong two-part learning effect was observed on CAORF: 1) a short-term effect exhibiting a high level of activity beginning with the four-hour watch and ending one or two hours later when the mate settles into slower and more routine watch behavior; and 2) a long-term effect, perhaps requiring several four-hour watches for the mate to settle into his normal routine. This learning effect is marked by relatively high levels of activity, high responsiveness to the demands of the experiment, and very cautious behavior. The learning effect, although resulting in substantial differences in mate behavior, is not considered as a major problem.

g. The mates' radar workload was found to be similar on CAORF and at-sea. This increased radar workload as observed on CAORF was attributed to the learning effect, similar to that observed for all other bridge tasks. The overly cautious mate behavior, a contributing part of the learning effect, may have resulted in differences in the type of radar behavior observed on CAORF during low difficulty situations; namely, a higher proportion of search/detection behavior, as opposed to contact analysis. The design layout characteristics of the CAORF bridge, as compared with the bridges on which the at-sea data were collected, may have added to the difference in the type of radar behavior observed during low difficulty periods. The CAORF bridge layout appears to be more efficient.

h. The finding that CAORF navigation activity differed with the at-sea activity was attributed to the equipment differences between the CAORF and at-sea bridges at the time of the validation runs. The relatively high emphasis placed by experimenters on collision avoidance as opposed to navigation was considered as a contributory factor.

i. The CAORF ship performance data exhibited trends similar to those of the at-sea data for traditional and automated bridges.

APPENDIX A

COMMENTS OF PROFESSIONAL MARINERS

Prior to formal experimentation, ship's masters and pilots were invited to work with CAORF to assess the realism, bridge layout, and the maneuverability of ownship. This resulted in adjustments to the bridge layout, to experimental procedures, and to the modeling of ownship to provide the "right" handling qualities. Some recommendations could not be implemented because of practical limitations. The following are selected comments with response or solutions:

COMMENTS	RESPONSE OR SOLUTIONS
a. When traffic ship disappears behind king post, shifting viewer's position cannot effect reappearance.	a. Control Station provides aspect to bridge upon request.
b. Add gyro repeaters and rudder angle indicator to facilitate watch officer's conning.	b. Units were added.
c. Radar reflection plotter has blind spot.	c. CAORF design reflects equipment limitation. This was not altered.
d. Ownship seems to respond too readily to rudder. Ownship seems to maintain swing too long after rudder has been returned to mid-ships.	d. These comments and similar ones led to corrections or adjustments by varying the appropriate coefficients for ownship model.

When a test subject completes a set of experiments, he is debriefed by the experimental group staff and is requested to prepare a critique. The critique may deal with any aspect of the experiment, facility, or personnel. The critiques were not intended to support validation but to find out whether the masters and mates operating in the CAORF environment felt as though they were aboard the bridge of an 80,000 DWT tanker. The following are excerpted from

various critiques:

- "The presentation on the screens, while not as good as real life, is still very good and I felt quite at home in estimating distances after I had practiced a while."

  "To me the size and several other details that I use in estimating distance check quite well with the actual distance away."

  "The visual detail of the ships that I normally get myself by just picking up the binoculars and looking, is different from normal and I could easily get along with this except in some fast problems when I felt a little pressed. The radar presentation on the Raytheon radar is very good. In fact it is just about the same as normal except that it does not show any sea return or other atmospheric phenomena that usually show on a radar. I felt right at home on this."

- "My involvement in the CAORF research program has been a pleasant and rewarding experience. CAORF is unique in every way. Standing watch, the problems become very real in every sense."

  "Research in all areas of bridge control and management are necessary. The increase in ship size, speed, and costs dictate that vessels be operated in the most efficient manner at sea and in confined waters. The simulator is very impressive as it can be programmed to carry out any maneuver; this would be impossible on a real ship. If the results of the research are published, it will no doubt influence the daily operating procedures if it is found changes should be made."

  "Being able to use the radar doing manual plotting and then using the collision avoidance system, proved to me this would be a very important piece of equipment aboard ship. The workload is a small fraction of the normal way. The CAS is simple to learn and the mistakes cut to a minimum in relation to manual plotting. The CAS would have to go through an acceptance program to be completely trusted at sea, but once used regularly, would become routine."

APPENDIX B

ANALYSIS OF FOG EFFECTS

B.1 INTRODUCTION

During a preliminary experiment, selected scenarios were run with a limited visibility condition (4 miles) imposed. When the limited visibility runs were analyzed, it became evident that a large variability existed in the range at which subjects first sighted vessels, although the visibility setting was not altered. The use of limited visibility scenarios was terminated pending investigation of this problem.

To gain an understanding of the variability in range at first sighting, the fog generation algorithms were analyzed and limited visibility tests were run on CAORF. This appendix presents the findings of these tests.

B.2 THEORETICAL CONSIDERATIONS

The effect of the fog or haze as it is programmed in CAORF is to cause objects at increasing range from the observer to gradually lose color and blend into the fog. An object which is brighter than the fog will appear to grow dimmer as it moves further away. Dark objects will actually appear to get brighter as they fade into the fog (approach the fog's color intensity). The approximation to the fog effect as used in CAORF is:

$$B = IB\ (2^{-Z/Zfog}) + IH\ (1 - 2^{-Z/Zfog})$$

where

- IB is the color intensity of an object
- IH is the color intensity of the fog
- Z is the distance from the object to the observer
- Zfog is the fog visibility setting

The first term may be thought of as the contribution of the object (vessel) to the resultant intensity, and the second term as the contribution of the haze.

Figure B.1 shows the growth of intensity of a dark object (IB = 0.07) fading into a white fog (IH = 1.0). Here IB is set at 0.07 which is the intensity of a tanker's hull at

CAORF. Thus, the equation above becomes:

$$B = 1 - 0.93(2^{-Z/Zfog})$$

and is shown in Figure B.1. The intensity of the hull increases until (for all practical purposes) its intensity is 1.0 and it is invisible in the fog. Figure B.2 shows the growth of intensity of a dark object (IB = 0.07) and the decay of intensity of a white object (IB = 1.0) in a "grey" fog (IH = 0.5).

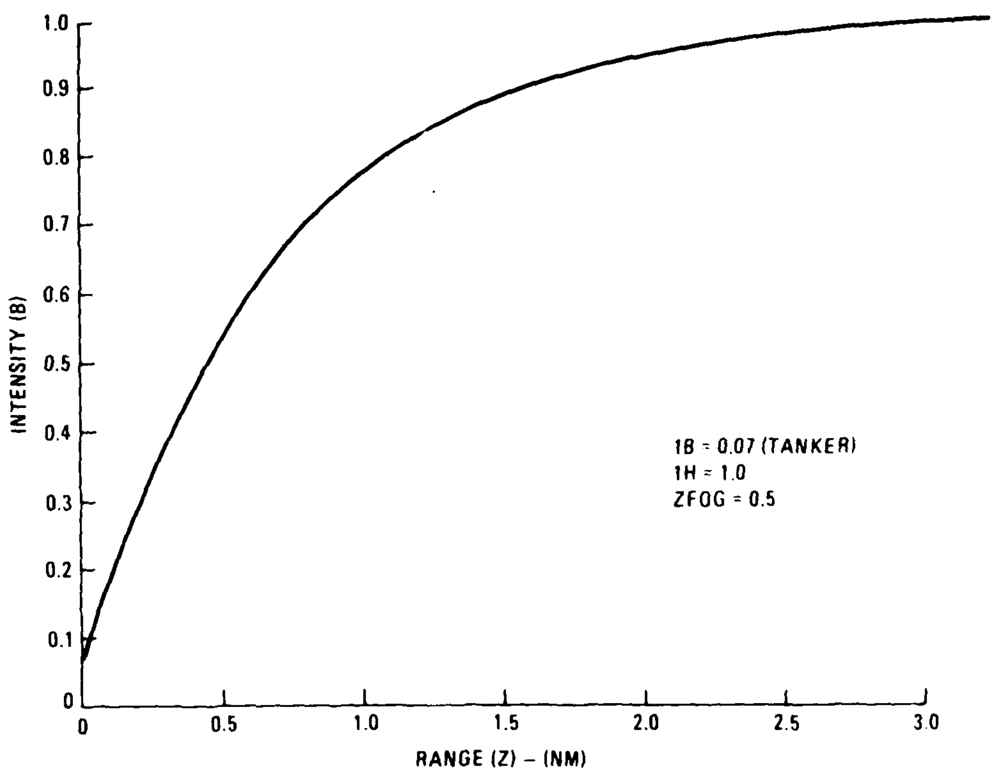

Figure B.1. Variation in Intensity of Ship's Hull in Fog, Dark Object-White Fog

Theoretically, a dark object will be visible against a white background if

$$\frac{I_w - I_o}{I_w} \geq 0.02$$

where I_w is the intensity of a white background (I_w = 1.0 for a white fog), and I_o is the intensity of the object. If this ratio falls below 2 percent, the object will be indistinguishable from the fog and fade into it. <u>Assuming</u> this ratio is constant, and is equal to the theoretical value of 0.02, it can now be shown that Z - Zfog is proportional to Zfog. Consider the case of a black object (IB = 0) fading into a white fog (IH = 1.0). The expression for B becomes:

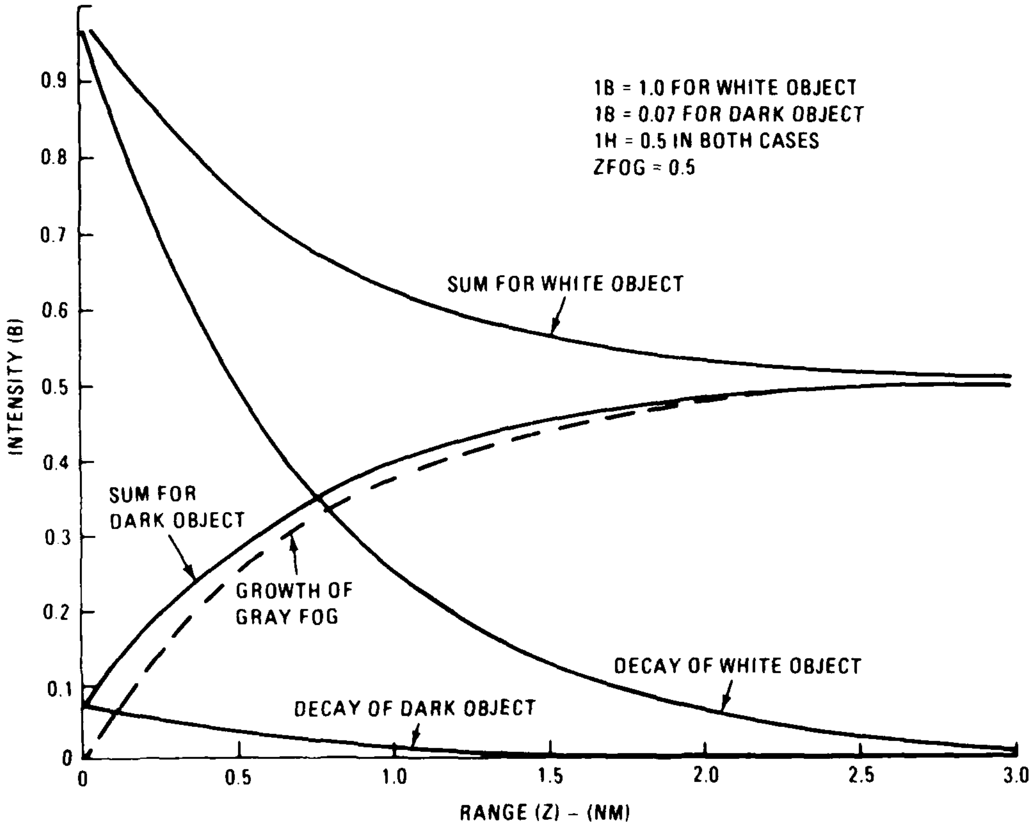

Figure B.2. Decay of Intensity of White Object and Growth of Intensity of Dark Object, Gray Fog

$$B = 1 - 2^{-Z/Zfog} \quad \text{or} \quad (1 - B) = 2^{-Z/Zfog}$$

and is shown in Figure B.3.

Setting this intensity difference (1 - B) equal to 0.02, we have

$$0.02 = 2^{-Z/Zfog}$$

as seen in Figure B.4.

Thus,

$$\log 0.02 = \frac{-Z}{Zfog} \log 2$$

therefore,

$$\frac{Z}{Zfog} = -\left(\frac{\log 0.02}{\log 2}\right)$$

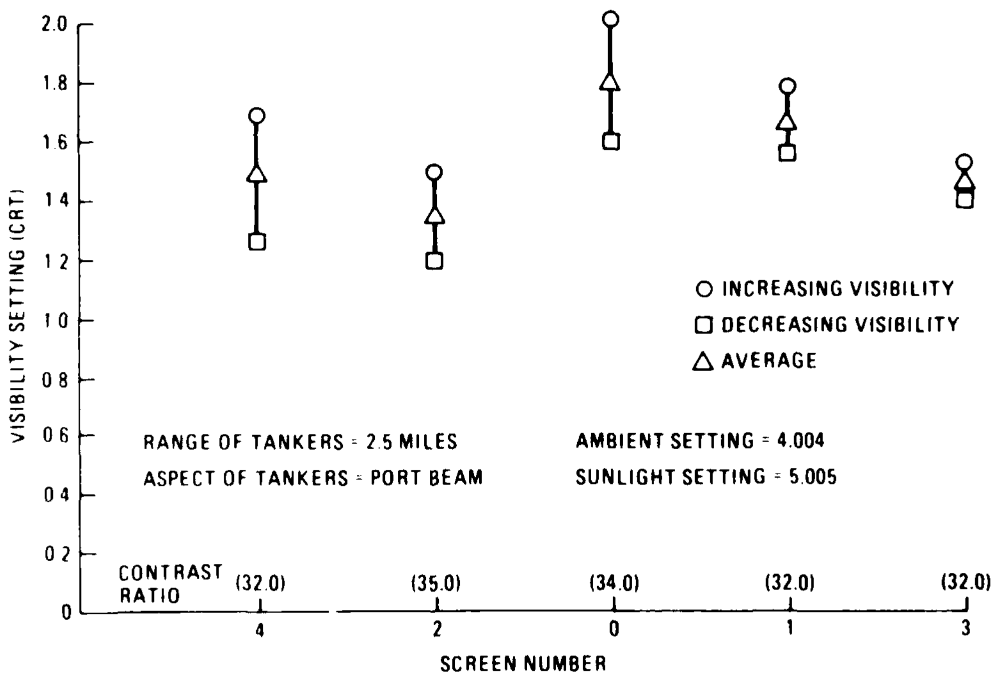

Figure B.3. Limited Visibility Range Test I

or

$$\frac{Z}{Zfog} - 1 = - (\frac{\log 0.02}{\log 2}) - 1$$

simplifying:

$$\frac{Z - Zfog}{Zfog} = K \qquad K = \text{a constant}$$

This has been illustrated in Figure B.5.

Therefore, the distance beyond the fog visibility setting at which a vessel is still visible should be proportional to the visibility setting. This is the most likely explanation for the variability in range at first sighting obtained during experimental runs of the first experiment under the limited visibility condition. Thus, at a 4-mile visibility setting, it can be expected that a target vessel will be visible over a wide range. Zfog, when set high, is equivalent to a "thin" fog. When Zfog is set to lower values, the

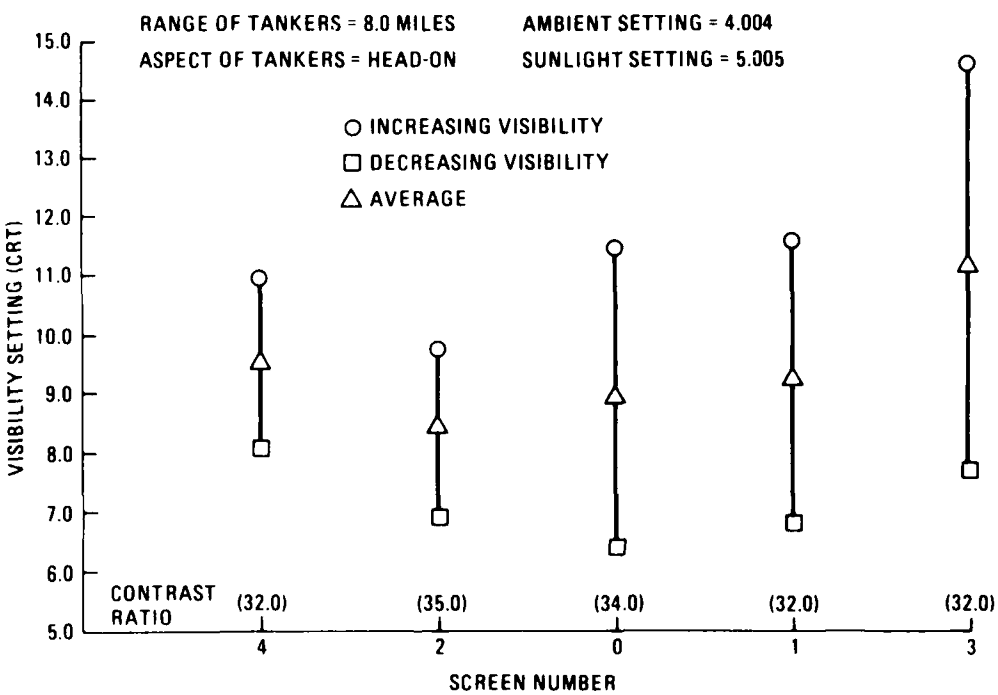

Figure B.4. Limited Visibility Range Test I

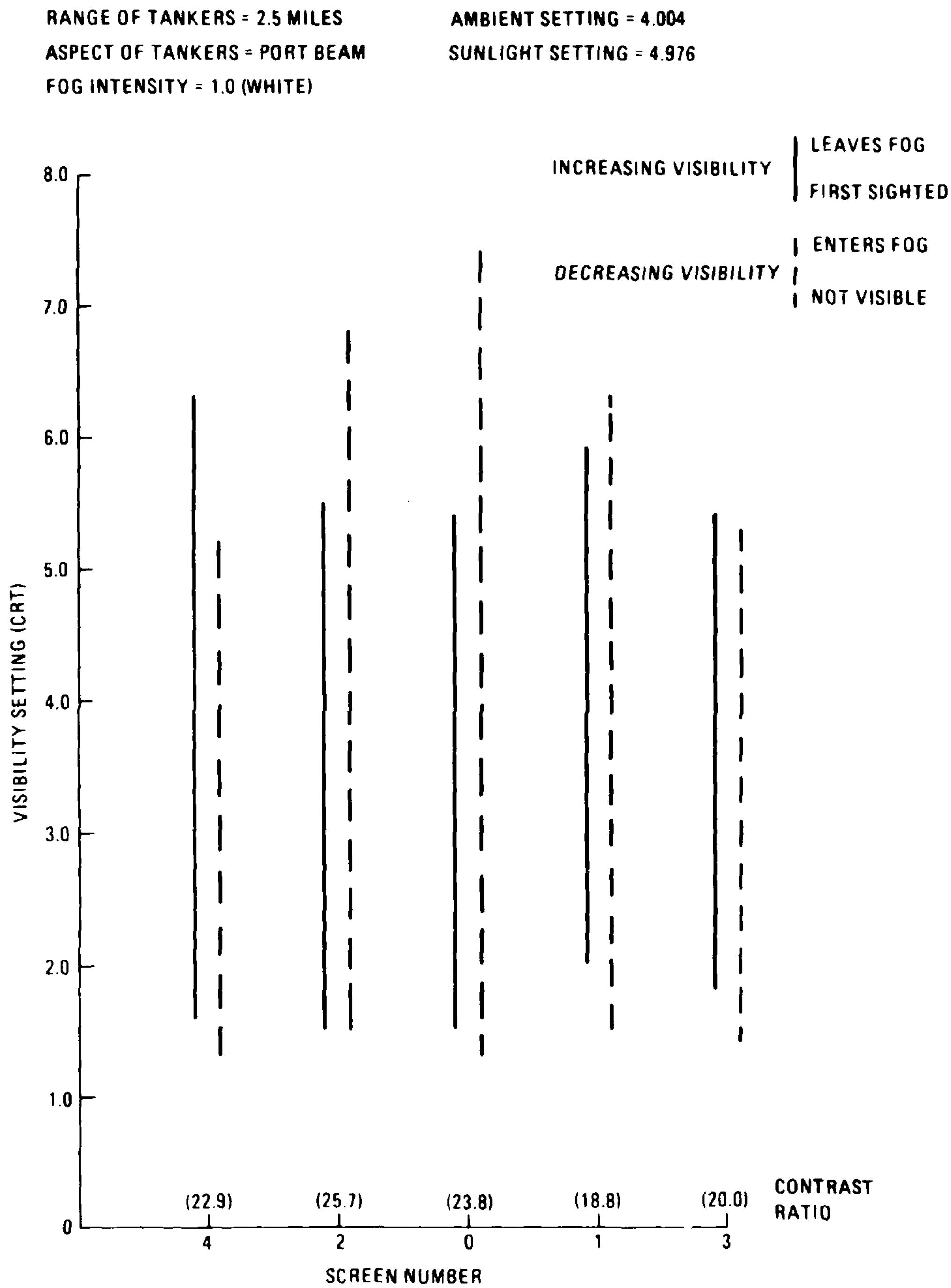

Figure B.5. Limited Visibility Range Test II

[illegible] range at first detection will decrease [illegible].

B.3 [illegible] LIMITED-VISIBILITY DATA COLLECTION

The following tests were conducted in order to provide an understanding of the limited visibility characteristics of CAORF.

B.3.1 Test I

The purpose of this test was to determine the variability of sighting distances for individual screens, and to establish a baseline for future tests.

One tanker was placed on each screen at a 2.5-mile range (port beam aspect). Visibility was raised until the ship appeared, then lowered until it disappeared. The visibility settings, from the CRT at the control station, were recorded at these points. The test was repeated with the vessels at 8 miles (head-on aspect). A CAORF observer was used for this test. See Figures B.3 and B.4.

B.3.2 Test II

Tankers were placed at 2.5 miles (port beam aspect) and the visibility was gradually decreased (fog rolling in). In this test, visibility readings were taken when it first became obvious that fog was covering the vessel, and again when the vessel disappeared. The object here was to get an insight into the extent or density of the fog. The test was then repeated for the fog moving out. The same observer was used in this test as in Test I. See Figure B.5.

B.3.3 Test III

This was a repeat of Test I except LNG carriers were used instead of tankers. It was thought that the color difference of the LNG carrier might be a factor in sighting distances; this test was thus included to determine if this were the case. The same observer was used as in Test I. See Figure B.6.

B.3.4 Test IV

The purpose of this test was to determine if a change in fog color would significantly affect the results. Test I was repeated except the fog was changed to a "grey" fog (IH = 0.5). See Figure B.7.

B.3.5 Test V

To obtain data over a range of vessel distances, Test I was run with ships at 0.5 mile (port beam aspect). See Figure B.8.

B.3.6 Test VI

To complete the set of data, Test I was run again with tankers at 0.25 and 1.0 miles. See Figures B.9 and B.10, respectively. Different observers were used at the two distances.

Two tests were also run using an experienced Master for sighting purposes. First, a ship was placed on each screen with a head-on aspect, and the visibility setting at 0.25. The observer indicated when the ship became visible through the fog. At these points, the range to the target was calculated. The visibility was also lowered until the bow of ownship was barely visible (setting = 0.05) and a target was sailed directly toward ownship. The target became visible through the fog at a range of 0.12 mile.

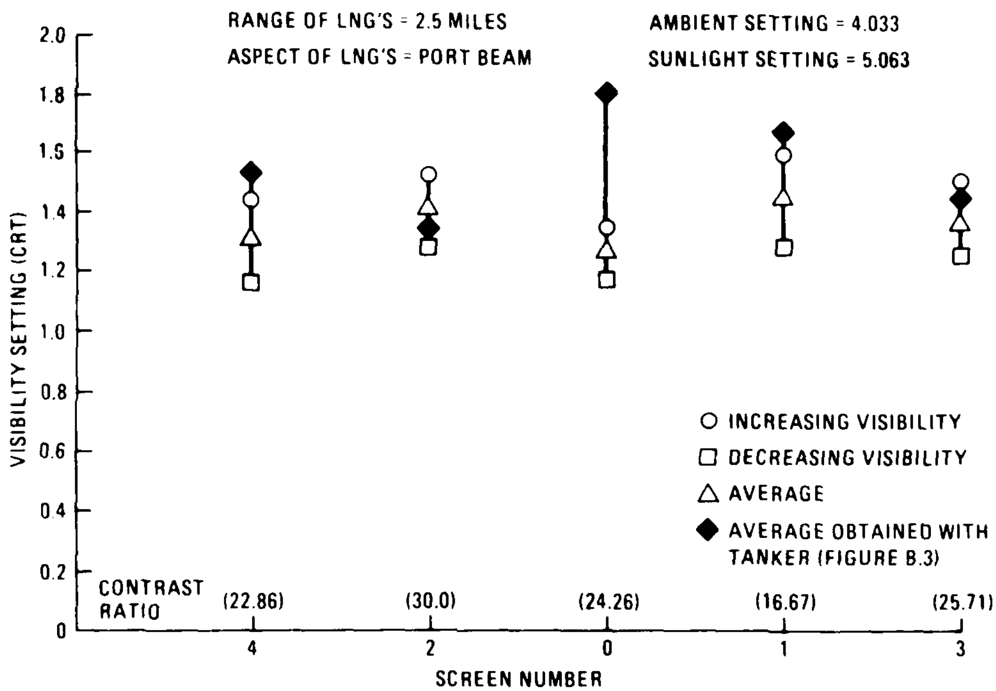

Figure B.6. Limited Visibility Range Test II

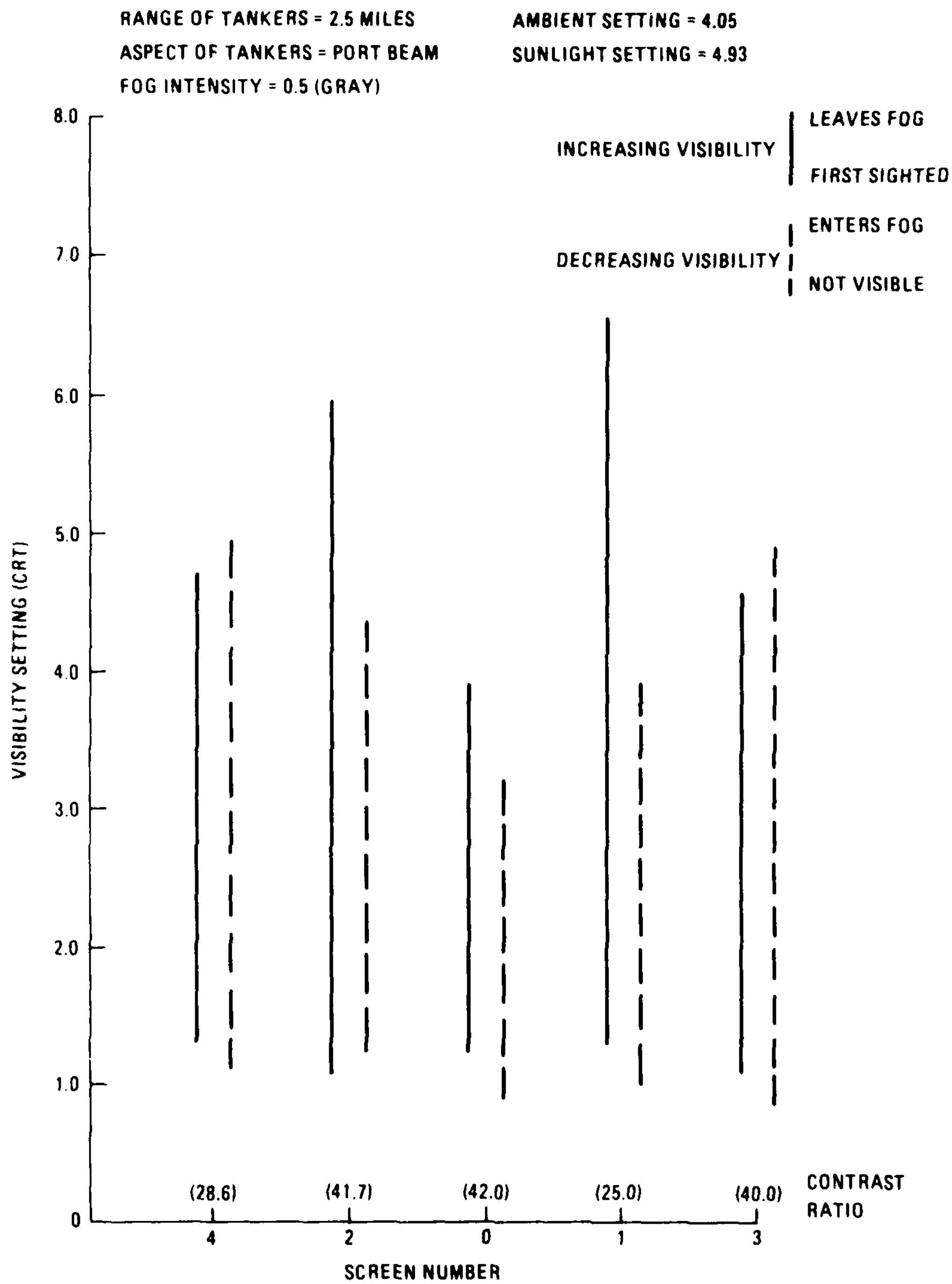

Figure B.7. Limited Visibility Range Test IV

For all tests (I - VI), the contrast ratio (black-white ratio) was obtained for each screen that day, and is indicated on the diagrams. Contrast ratio is measured at the beginning of every day, using a spot photometer. The hull of a ship is used for the black measurement, and the brightest part of the screen for the white.

B.4 RESULTS

For Test III, as described, LNG carriers were used instead of tankers, to determine if vessel color played a part in sighting distance. Since the vessel's hull is the last part of the ship to fade into the fog, and $I_{hull} = 0.07$ for both LNG carriers and tankers, only slight differences were obtained for the two tests.

Changing the fog color in Test IV did not appreciably affect test results. It was suggested that with the dark fog a vessel would disappear more rapidly, but visibility settings were actually slightly lower in a dark fog than in a light one. An explanation for this may be the condition of the projectors on that particular day. Contrast ratios were slightly higher for the dark-fog test than for the light-fog one.

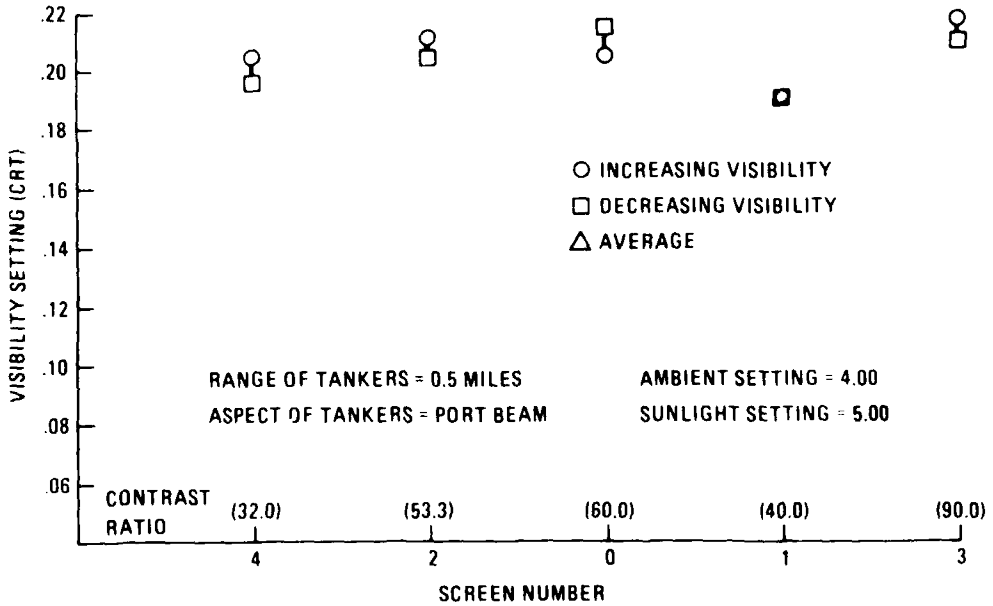

Figure B.8. Limited Visibility Range Test V

Using the data collected, it is also possible to analyze the effect (if any) of the sunlight direction. Sunlight originated in the southeast for these tests. Thus, when an observer in ownship (heading north) is looking at a vessel on Screen 2, he is seeing the sunlight-illuminated side of the target ship, and when looking at a vessel on Screen 3, he is looking at the shadowed portion of the ship. The experimental data does not show any consistent difference between readings taken on these two screens.

From the experimental data collected, curves of ship range versus visibility setting were constructed. Figures B.11, B.12, and B.13 present data for target ranges up to 1 mile ("short range") and Figure B.14 for ranges up to 8 miles ("long range").

Figure B.11 presents the data obtained for tests when the visibility was being reduced until the vessel was no longer visible. The horizontal width across the cross-hatched portion of the curve indicates the change of visibility settings required to make the target vessel at that range disappear. This cross-hatched portion has been labeled "Region of Doubt" because, for a particular visibility setting, a vessel may or may not be visible at the ranges within the cross-hatched region, depending on the displaying screen, the contrast ratio for that day, eyesight of observer, etc.

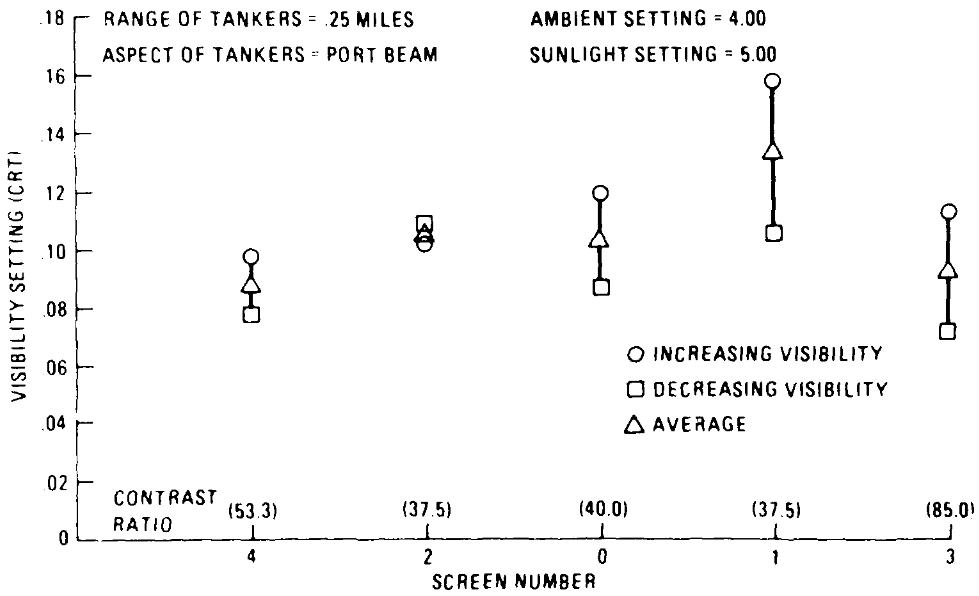

Figure B.9. Limited Visibility Range Test VI

The area labeled "Visible Region" defines the ranges at which, for a particular visibility setting, a vessel will almost certainly be visible, according to the data collected.

The area of most interest is labeled "Invisible Region." At these ranges, for a certain visibility setting, the fog will completely obscure the vessel and it will not be seen.

Figure B.12 is similar to Figure B.11, the only difference being that all data presented here were collected from tests in which visibility was being increased.

Figure B.13 is a composite of Figures B.11 and B.12, with the cross-hatched region applicable to vessels either going into or coming out of the fog. The composite diagram for ranges up to 8 miles is shown in Figure B.14, with the cross-hatched area having the same significance as the same region in Figure B.13. Thus, to ensure, for example, that a

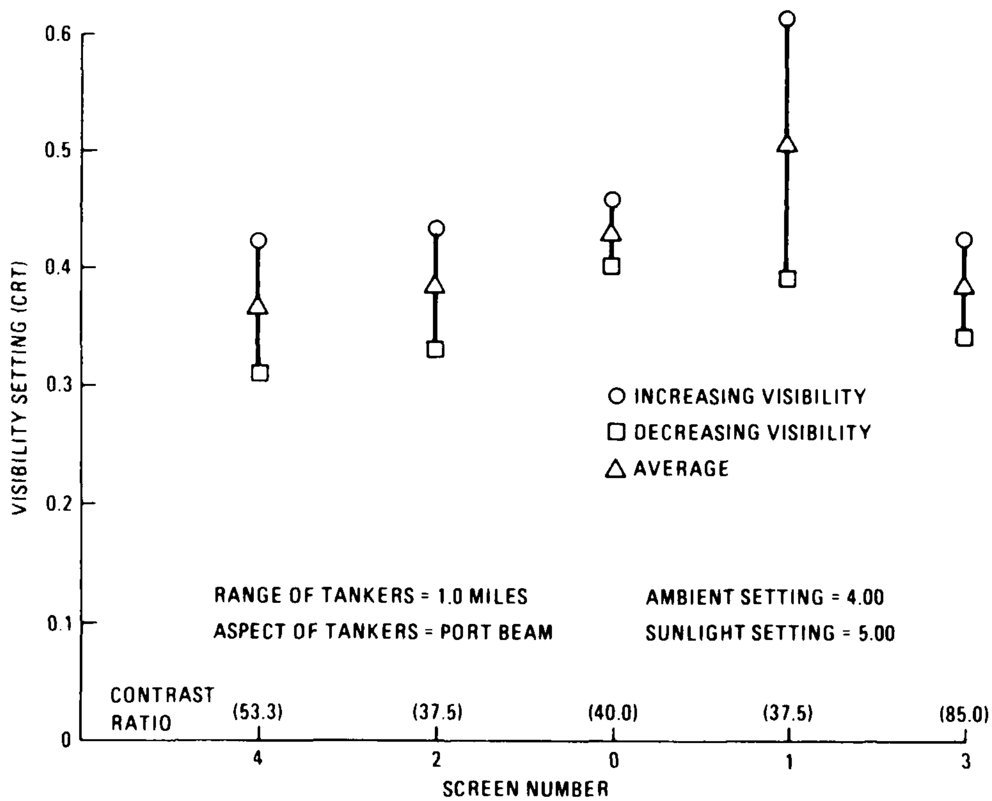

Figure B.10. Limited Visibility Range Test VI

vessel will not be visible beyond 0.5 mile, a visibility setting of 0.15 or less should be chosen. It may be advisable not to get too close to the region boundary lines, however; a better choice for visibility setting for this example might be 0.125 (or less).

B.5 CONCLUSIONS AND RECOMMENDATIONS

a. This appendix presents information useful for planning future limited visibility experimental runs with the existing fog algorithms.

b. The variability in range over which a vessel can first be detected is proportional to the fog setting. Experimental runs with low Zfog settings (one mile or less) will have a relatively low variability in detection range, and the problems encountered during the aborted experiment (with Zfog settings at 4.0 miles) should thus be resolved.

c. A more precise method of fixing the distance at which a vessel first becomes visible in fog might be required.

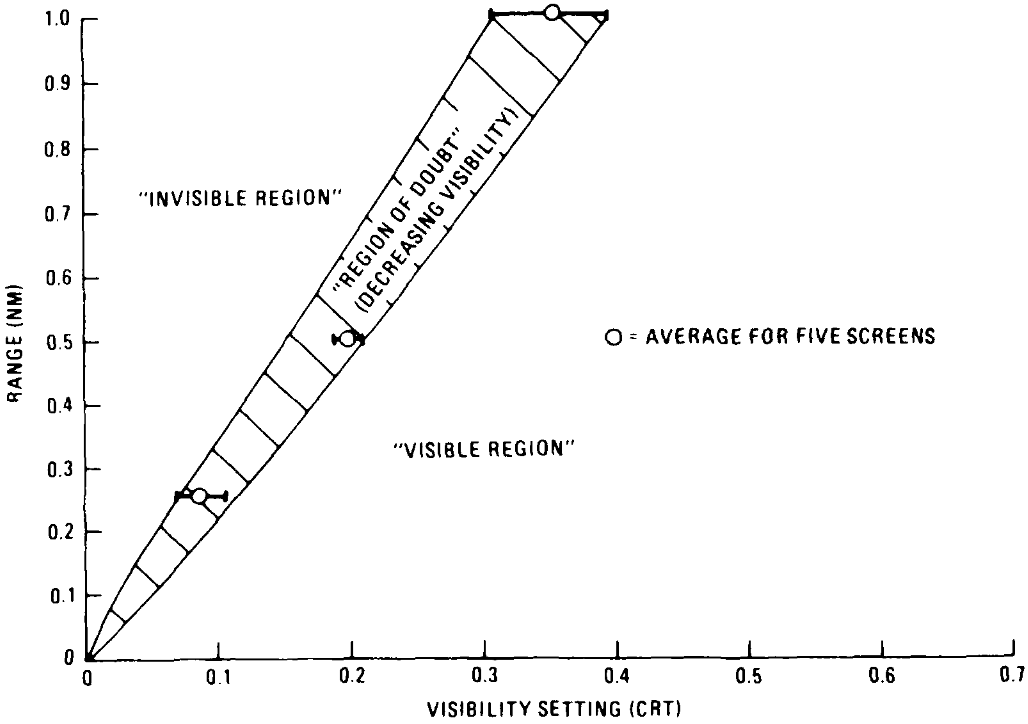

Figure B.11. Short Range, Decreasing Visibility Calibration Curve

The fog algorithms could be modified; e.g., a "fog range factor" to determine the beginning of the fog, along with a "fog density factor", to determine the "thickness" of the fog could be programmed. Another possibility is to inhibit the appearance of a ship image beyond a specified range.

d. The experimental data does not show any consistent difference in the visibility of a ship as a function of sun angle in limited visibility conditions.

e. Ship type and color do not materially influence the range at first sighting.

f. Changing the color of fog to grey did not appreciably affect ranges at which ships were obscured by fog.

g. Variability between screens was not found to be an important factor, except when a screen had a particularly low contrast ratio for that day. Otherwise, the screens were fairly consistent.

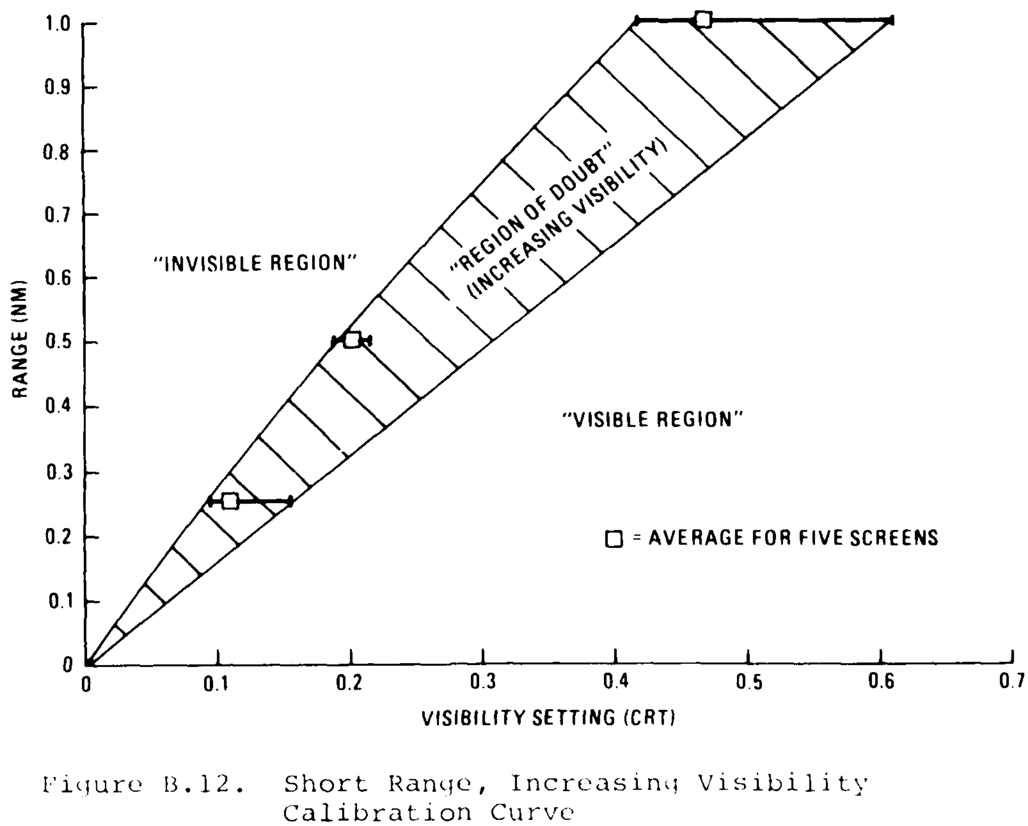

Figure B.12. Short Range, Increasing Visibility Calibration Curve

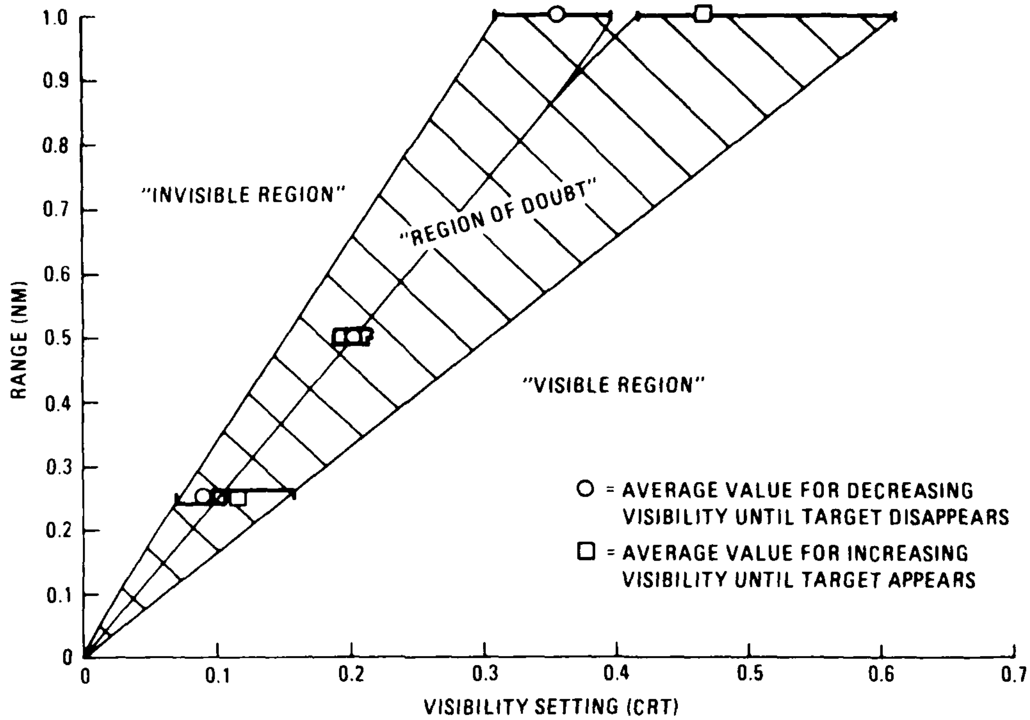

Figure B.13. Short Range Limited Visibility Calibration Curve

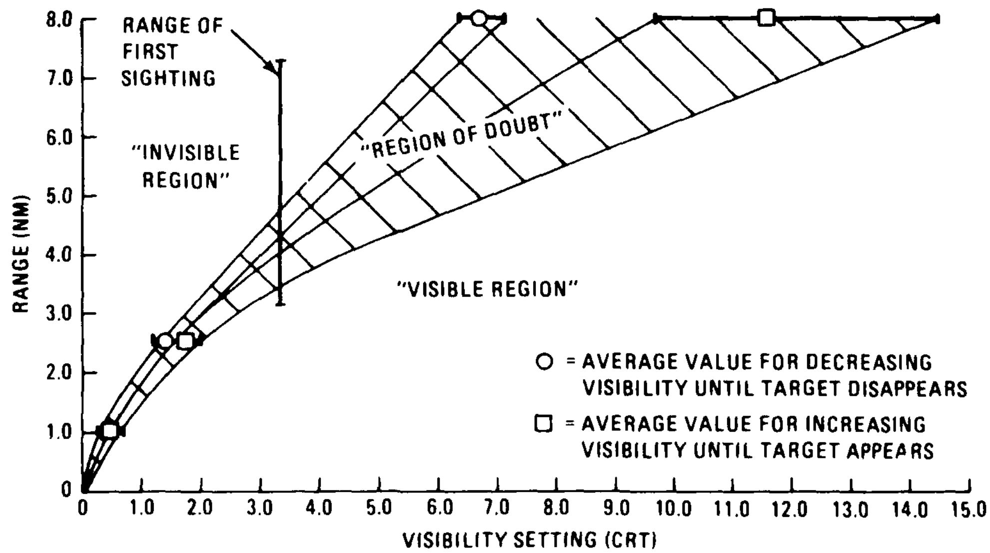

Figure B.14. Long Range Limited Visibility Calibration Curve

APPENDIX C

DESCRIPTION OF CAORF

C.1 INTRODUCTION

CAORF is a sophisticated ship-maneuvering simulator operated by the U.S. Maritime Administration for controlled research into man-ship-environment problems. Controlled experiments, which might require several vessels, cannot be performed readily in the real world and would certainly be ruled out for testing situations that involve potential danger. Such experiments can be performed safely and easily at CAORF. A simplified cutaway of the simulator building is shown in Figure C.1 and the relationships among the major subsystems are illustrated in Figure C.2.

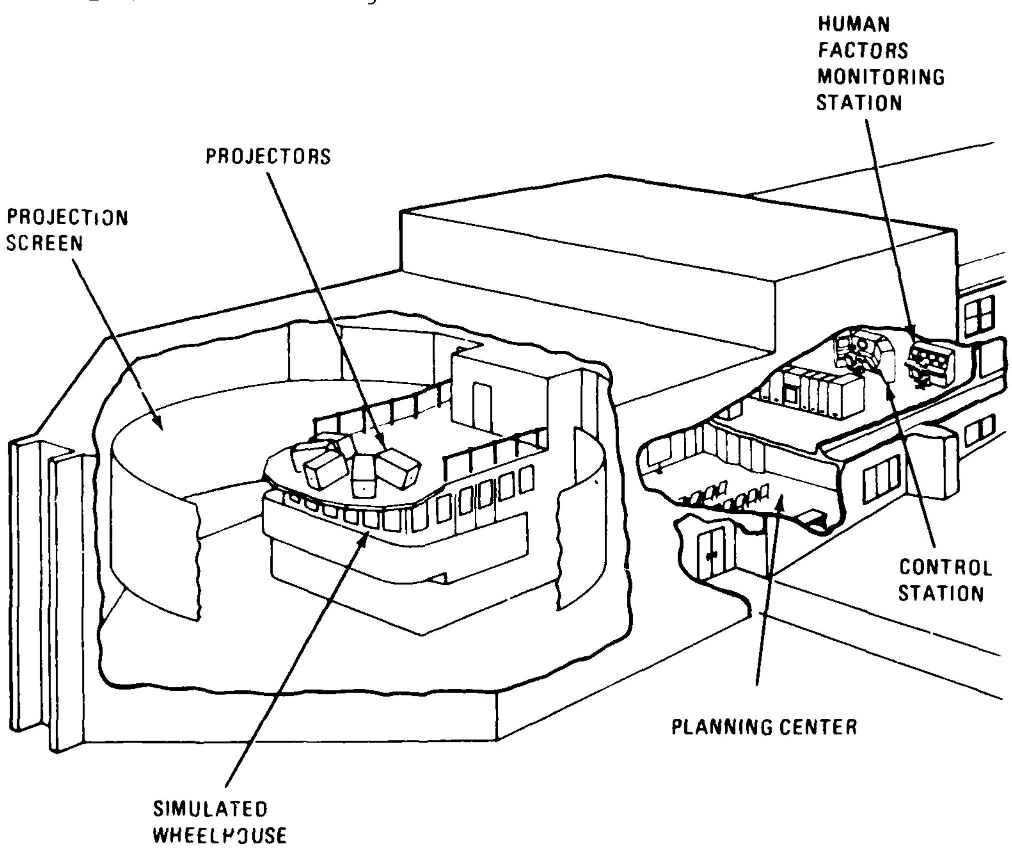

Figure C.1. Cutaway - CAORF Ship Simulator

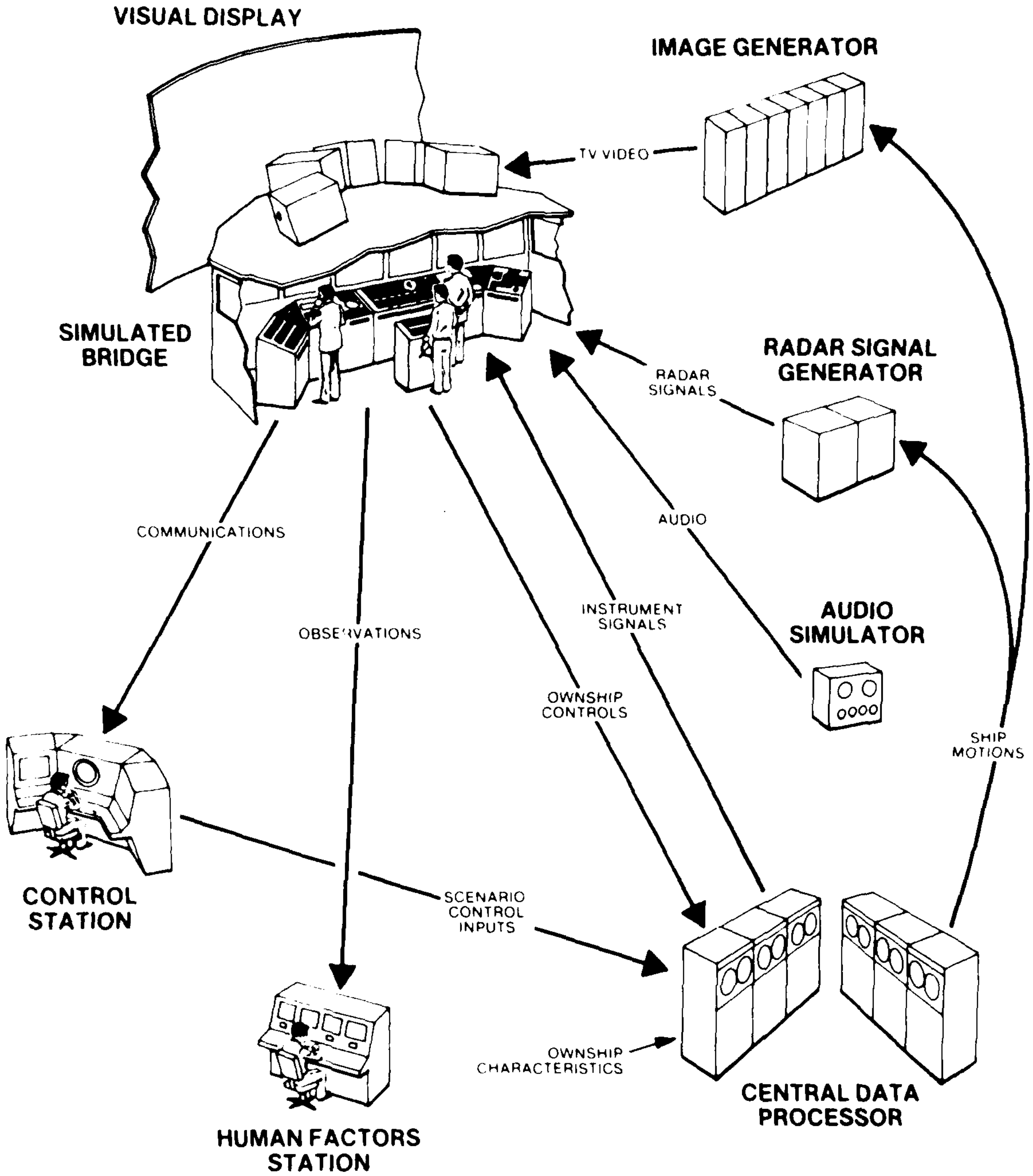

Figure C.2. CAORF Ship Simulation Subsystems

All actions called for by the watch officer on the bridge are fed through a central computer that alters the visual scene and all bridge displays and repeaters in accordance with the calculated dynamic response of ownship and the environmental situation being simulated. CAORF has the capability of simulating any ship, port, or area in the world. The major subsystems are:

- Wheelhouse which contains all the equipment and controls needed by the test subject watch officer to maneuver ownship through a scenario, and includes propulsion and steering controls, navigational equipment, and communication gear

- Central Data Processor which computes the motion of ownship in accordance with its known characteristics, models the behavior of all other traffic ships, and drives the appropriate bridge indicators

- Image Generator which constructs the computer-generated visual image of the surrounding environment and traffic ships that is projected onto a cylindrical screen for visual realism

- Radar Signal Generator which synthesizes video signals to stimulate the bridge radars and collision avoidance system for the display of traffic ships and surrounding environment

- Control Station from which the experiment can be monitored and (if desired) traffic ships and environment can be controlled

- Human Factors Monitoring Station from which unobtrusive observation and video recording of test subject behavior may be carried out by experimental psychologists

C.2 SIMULATED BRIDGE

The simulated bridge consists of a wheelhouse 20 feet (6.1m) wide and 14 feet (4.3 m) deep. The equipment on the CAORF bridge is similar to that normally available in the merchant fleet and responds with realistically duplicated time delays and inaccuracies. The arrangement is based on contemporary bridge design. It includes:

- Steering Controls and Displays - a gyropilot helm unit with standard steering modes, rate of turn

indicator, rudder angle/rudder order indicators, and gyro repeaters

- Propulsion Controls and Displays - an engine control panel (capable of simulating bridge or engine room control), containing a combined engine order telegraph/throttle, an rpm indicator and a switch for selecting the operating mode such as finished with engine (FWE), warm up, maneuvering and sea speed

- Thruster Controls and Display - bow and stern thrusters and their respective indicators and status lights

- Navigation Systems - two radars capable of both relative and true motion presentations plus a collision avoidance system. Capability exists for future additions such as a digital fathometer, RDF (Radio Direction Finder), Loran C, and Omega systems

- Communications - simulated VHF/SSB radio, docking loudspeaker (talkback) system, sound powered phones and ship's whistle

- Wind Indicators - indicate true speed and direction of simulated wind.

C.3 OWNSHIP SIMULATION

Any ship may be simulated at CAORF. The computerized equations of motion are adapted to the ship by changing specific coefficients among which are hydrodynamics, inertial, propulsion, thruster, rudder, aerodynamic, etc. Wind and currents realistically affect ship motion according to draft (loaded or ballasted) and relative speed and direction. Ownship's computer model was validated by comparing various simulated maneuvers (e.g., zig-zag, turning circle, and spiral tests, crash stops and acceleration) with actual sea trial data.

C.4 IMAGE GENERATION

The visual scene is duplicated on CAORF to a degree of realism sufficient for valid simulation. The scene includes all the man-made structures and natural components of the surrounding scene that mariners familiar with the geographical area deem necessary as cues for navigation. Thus, bridges, buoys, lighthouses, tall buildings, mountains,

glaciers, piers, coastlines, and islands would be depicted in the scene. In addition, the closest traffic ships and the forebody of ownship appear. All elements in the scene, except ownship's forebody, appear to move in response to ownship's and other ship's maneuvers. The sky is depicted without clouds and the water without waves.

For enhanced realism the scene is projected in full color. The perspective is set for the actual bridge height above waterline for the simulated ship. Shadowing can be varied according to the position of the sun at different times of day.

Environmental conditions also affect the scene. The lighting can be varied continuously from full sun to moonless night. At night, lights can be seen on traffic vessels, buoys, piers, and other points ashore. Visibility in day or night can be reduced to simulate any degree of fog or haze.

C.5 RADAR SIGNAL GENERATION

The Radar Signal Generator produces real-time video signals for driving the two radar PPIs. The items displayed are synchronized with the visual scene and include navigation aids, ships, shoreline and other topographical features with appropriate target shadowing, clutter, range attenuation, and receiver noise. The radar gaming area which covers an area of 150 by 200 nautical miles, extends beyond the visual gaming area, which is 50 by 100 nautical miles. Within the radar gaming area, as many as 40 moving traffic ships can be displayed. The radar signal generator also drives the collision avoidance system, which can be slaved to either of the master PPIs.

C.6 CONTROL STATION

The Control Station (Figure C.2) is the central location from which the simulator experiment is controlled and monitored. An experiment can be initiated anywhere within the visual gaming area with any ship traffic configuration. The control station enables the researchers to interface with the watch-standing crew on the bridge, to simulate malfunctions, and to control the operating mode of the simulator. The Control Station is also capable of controlling motions of traffic ships and tugs in the gaming area and simulating telephone, intercom, radio (VHF, SSB) and whistle contact with the CAORF bridge crew.

C.7 HUMAN FACTORS MONITORING STATION

The Human Factors Monitoring Station (Figure C.2) is designed to allow collection of data on crew behavior. Monitoring data is provided by five closed-circuit TV cameras and four microphones strategically located throughout the wheelhouse to record all activities, comments and commands.

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